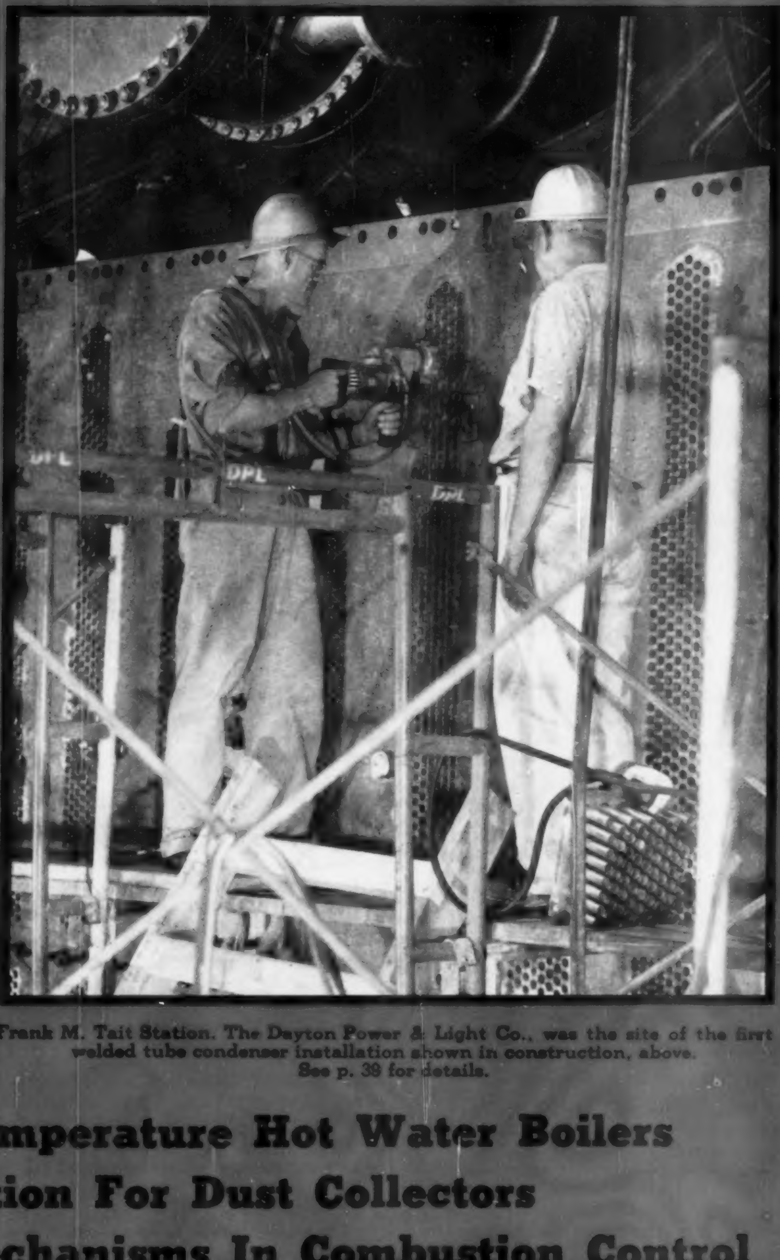
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

August 1957



Frank M. Tait Station. The Dayton Power & Light Co., was the site of the first welded tube condenser installation shown in construction, above.
See p. 39 for details.

High Temperature Hot Water Boilers

Automation For Dust Collectors

Servomechanisms In Combustion Control

Throttling Wet Steam

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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Feature Articles

Editorials

Departments

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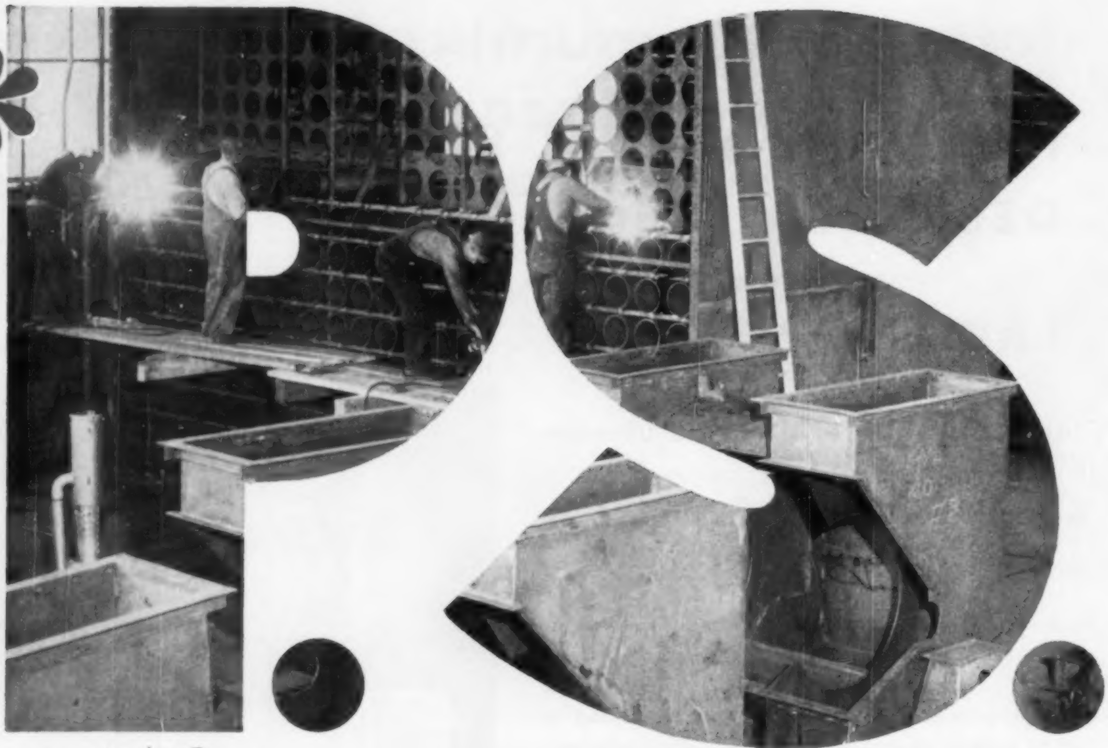

P.S.

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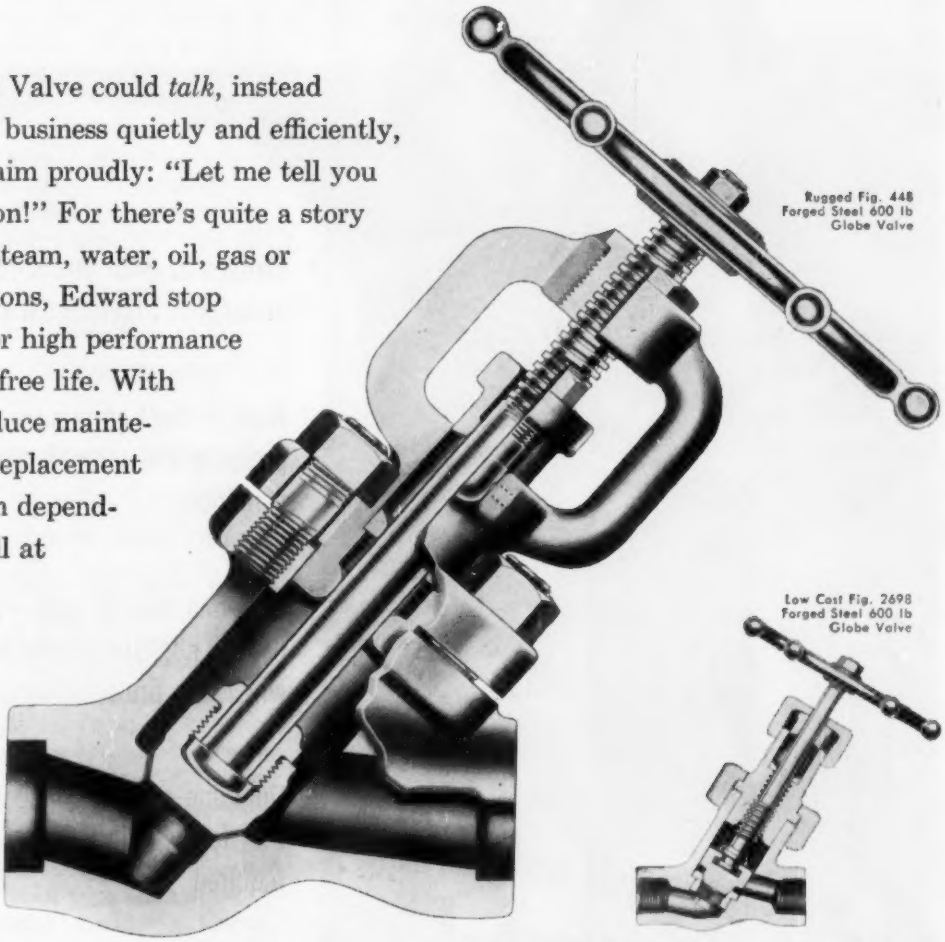

Rugged Fig. 448
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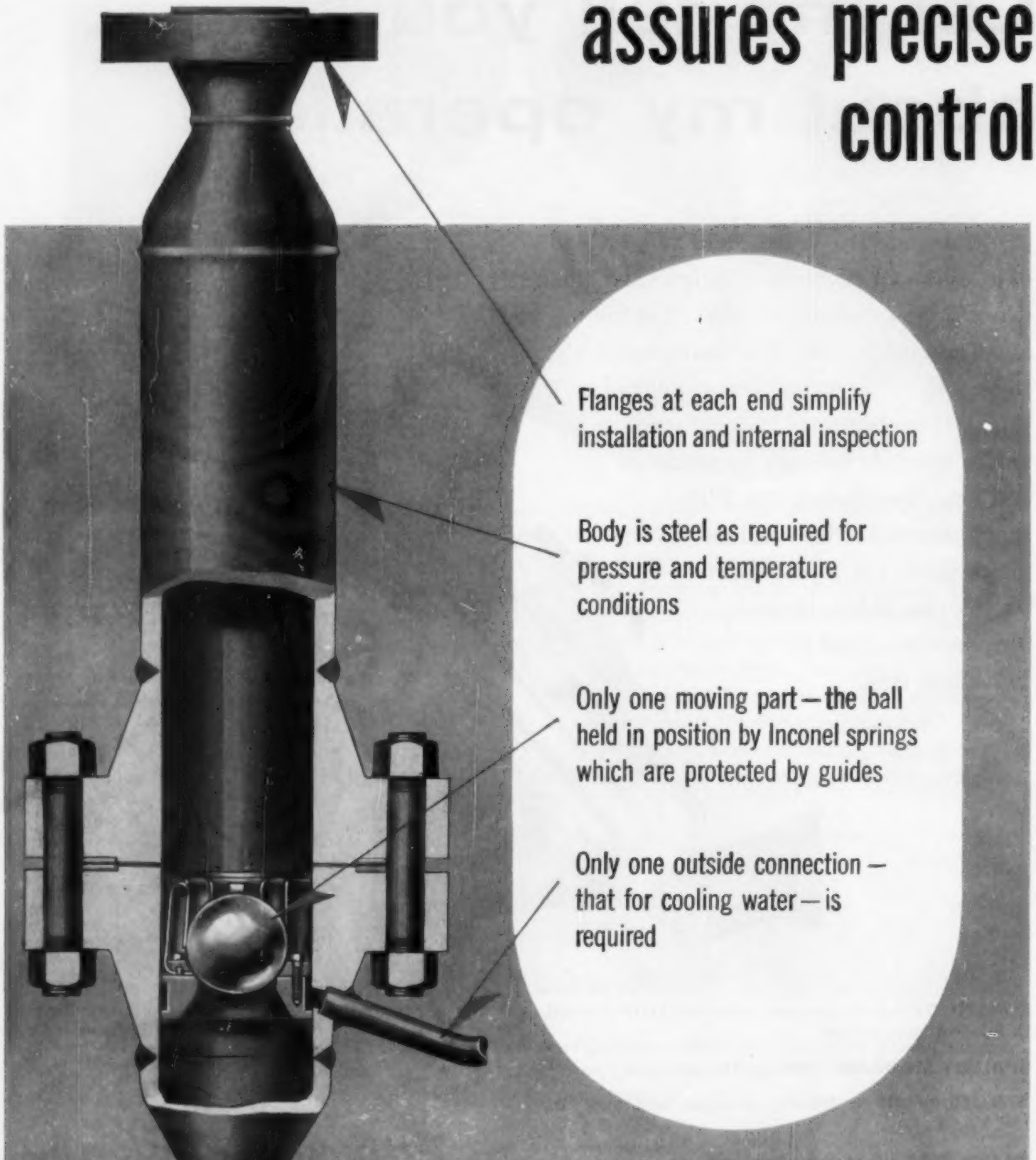

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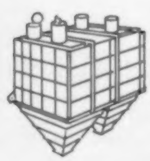

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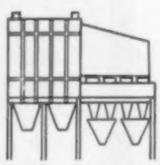

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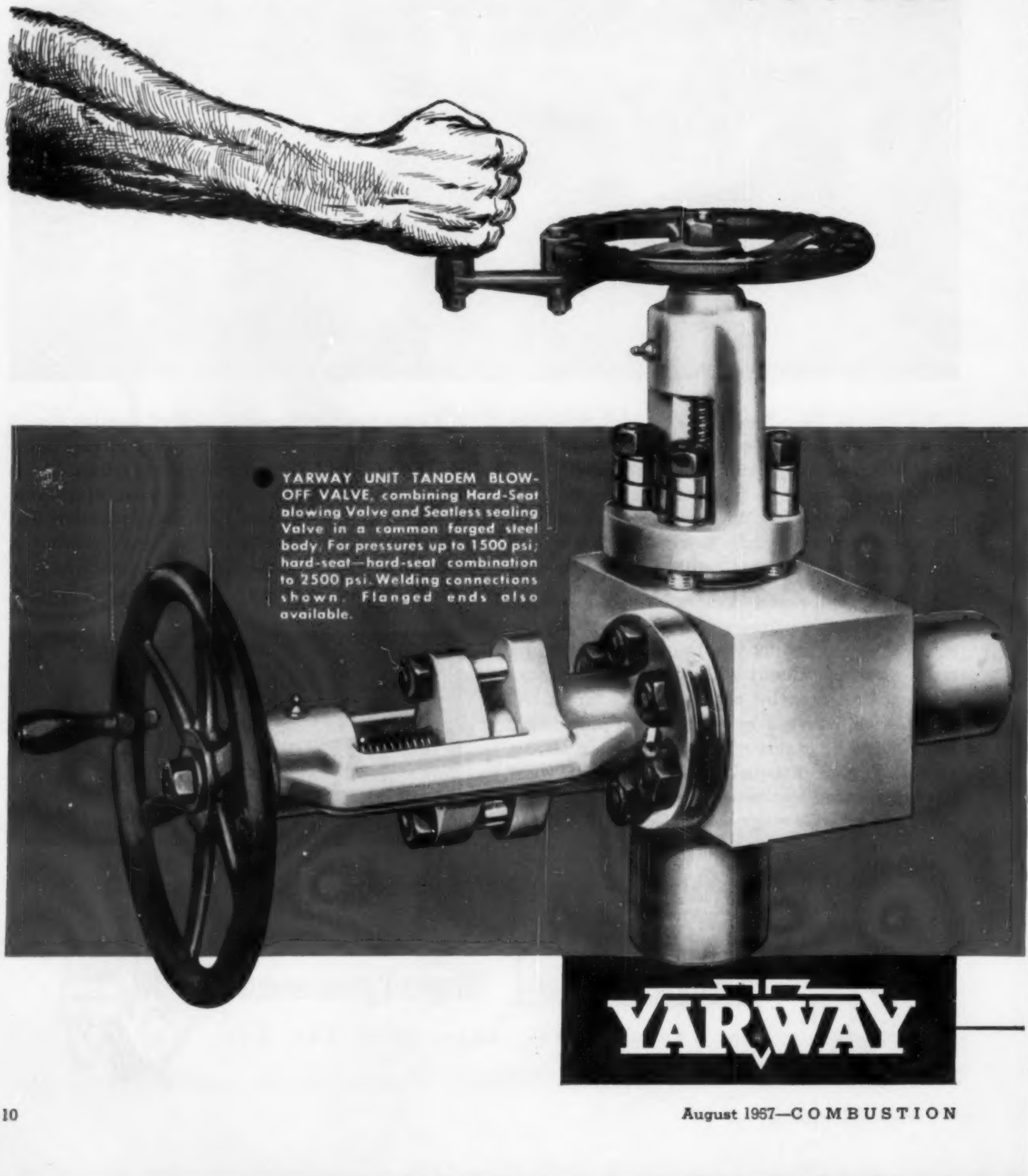
YARWAY UNIT TANDEM BLOW-OFF VALVE, combining Hard-Seat blowing Valve and Seatless sealing Valve in a common forged steel body. For pressures up to 1500 psi; hard-seat—hard-seat combination to 2500 psi. Welding connections shown. Flanged ends also available.
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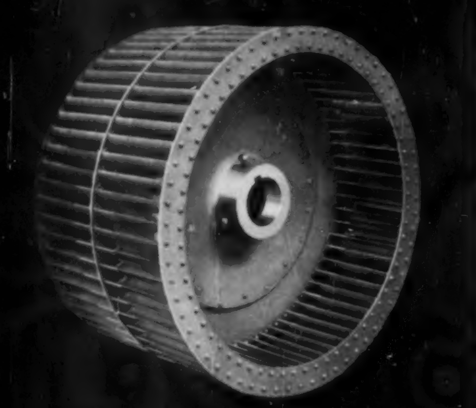

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Hall Industrial Water Report

VOLUME 5 AUGUST 1957 NUMBER 4

Many Contaminants Can Get into Boiler Feedwater

The boiler is the sump in which all solids present in the feedwater must tend to accumulate. Normally, condensate returned to the boiler is relatively pure and the usual solids in the additional make-up water are handled routinely by chemical treatment and blowdown. When unexpected contamination of feedwater does occur, quick action is necessary to avoid serious trouble due to carryover, corrosion or tube losses. The Hall engineer is specially trained to help the plant operators locate the source of the contamination and get boiler water conditions back to normal.

Get the Lead Out

When an eastern utility plant first opened a new high-pressure turbine, unexpected deposits were found on the blades in the reheat section. Even more unexpected was Hall Laboratories finding that the deposits were composed largely of lead silicate, an unprecedented constituent of such deposits.

A careful search for the source of the lead by plant engineers covered the entire boiler-turbine system and ended at the condenser. At start-up, considerable leakage had occurred between the condenser shell and tube sheets and between tube sheets and water boxes. When red lead compound was forced into the joints to seal the leaks, appreciable amounts had flowed between the tube sheets and shell into the steam space.

How did the lead get to the turbine? Slowly dissolving in the condensate, the lead oxide passed to the boiler in the feedwater, distilled off along with silica in the steam and deposited as lead silicate when decrease in temperature and pressure made the steam no longer capable of carrying it. Thorough cleaning of the steam space of the condenser was necessary to correct the problem.

Diagnosis by Odor

Hall field engineer R. M. Jordan was called to a paperboard plant to solve a bad carryover problem which had developed because of contamination of the boiler water. A major clue was an odor of burned sugar throughout the plant and in the surrounding area.

Because of previous training and experience, Jordan's first question was whether any plant operation involved the use of starch. This led directly to the department where a starch base adhesive was prepared by indirect heating with steam. There a leak in the steam coil was found which had permitted siphoning of adhesive into the condensate line when the steam was shut off. Decomposition of the starch in the boiler resulted in foaming of the boiler water and in the odor of burned sugar in the steam.

Raw Water Instead of Raw Carrots

When a foaming problem developed at an eastern food processing plant, the experienced operators looked for a leak at a kettle with resulting contamination of the condensate with some vegetable product. When they were unable to trace the problem to the usual sources they called Hall field engineer D. H. Pyle.

Pyle's first move was to analyze the boiler water. He found no phosphate even though a satisfactory amount had been reported shortly before the foaming started. Conductivity was very little greater than it had been earlier, indicating no great change in dissolved solids. However, the concentration of suspended solids was abnormally high.

The signs pointed to raw water contamination of condensate. Hardness determinations on the various condensate streams quickly revealed raw water leakage in a group of tubular water heaters. With this information the operators were able to stop the contamination and to get boiler water conditions back to normal in short order.

Anti-freeze in Boilers

Late one afternoon Hall field engineer E. A. Ramalho received a call from a mid-western food processing plant in real trouble. Total solids concentration of the boiler water was far too high. Carryover was occurring. Despite increased feeding of phosphate and alkali, adequate concentrations could not be maintained in the boiler water.

Arriving at the plant, Ramalho had the operators give the boilers more blowdown and greatly increase phosphate and alkali feeding to maintain tolerable conditions in the boiler water until the source of the difficulty could be located.

Finding the point of contamination was not easy because of the large numbers of return lines and pieces of steam condensing equipment to be checked. However, Ramalho and the operators gradually narrowed down the search. Finally, in the wee hours of the morning, they found a leak in a small exchanger heating calcium chloride brine. Arrangements were immediately made to discard the condensate from this heat exchanger and further mopping up operations were easily accomplished.

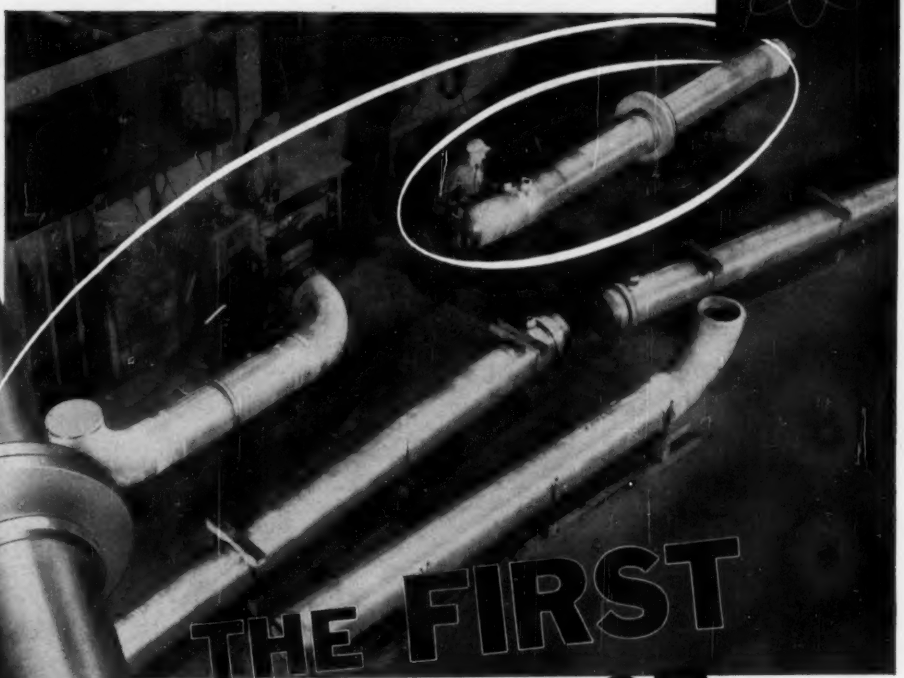
Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information, write, wire or call Hall Laboratories, Division of Hagan Chemicals & Controls, Inc., Hagan Building, Pittsburgh 30, Pa.

Water is your industry's most important raw material. Use it wisely.

Hall Laboratories—Consultants on Procurement, Treatment, Use and Disposal of Industrial Water

ALL IN A DAY'S WORK AT *Pittsburgh Piping*



THE FIRST PIPING FOR ATOMIC POWER

Fabricated section in foreground is austenitic steel piping—the first fabricated for the world's first big atomic-power central station. Other components of this system are shown at the right.

This piping is a record maker—being the first ever made for a big atomic-power plant—the Duquesne Light Shippingport station. This job, while challenging, was facilitated by employing the techniques which we had previously developed for fabricating austenitic steel piping for central stations operating at steam temperatures of 1050°F. and higher, as well as for the *Nautilus*. In fact, Pittsburgh Piping was among the first to fabricate stainless steel piping—for the process industries, in 1927. And, we pioneered the use of stainless steel piping materials in the power field. We have the experience and the facilities—use them on your high temperature, high pressure piping jobs.

FREE TECHNICAL BULLETIN ON PIPING MATERIALS

This bulletin reports an intensive investigation into the problem of main steam piping materials and gives data on the stress rupture characteristics of Types 316 and 347 stainless steel piping adjacent to welded joints.

PP-33

Promoting Progress **IN POWER AND PROCESS PIPING**

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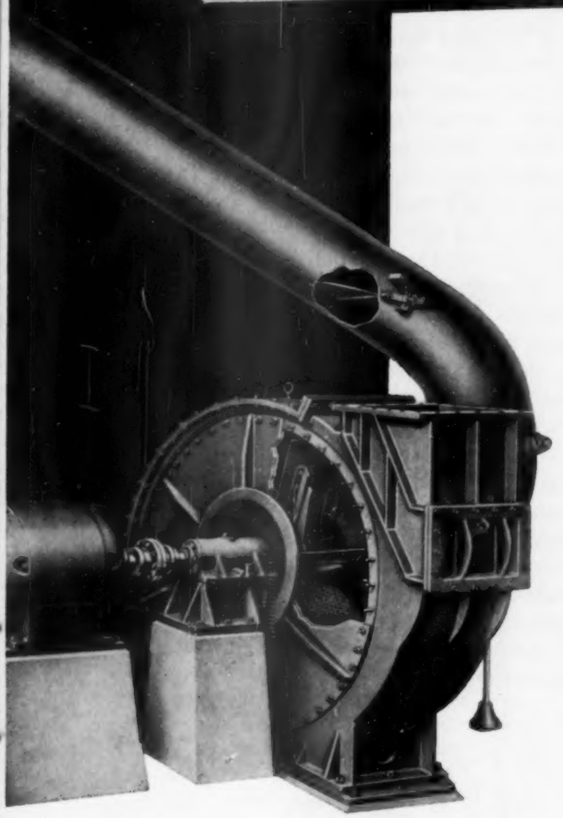
A first-class pulverizer should possess certain basic capabilities of which the following — most operators will agree — are the most important. They are the ability to . . .

- ***handle high moisture fuels without difficulty***
- ***operate with low power requirement***
- ***stay in continuous service for long periods***
- ***operate with low maintenance costs***
- ***permit convenient control of fineness while running***
- ***adjust grinding pressure automatically***
- ***lubricate, when required, while in operation***
- ***operate quietly and without vibration***

It is because the C-E Raymond Bowl Mill measures up on *all* these points that it has long been regarded by many leading power engineers as the country's No. 1 pulverizer. The reasons why the Bowl Mill is an outstanding all-around performer are summarized below.



HIGH MOISTURE — **The most effective means of achieving good pulverizing results with high moisture fuels (16 — 18% — Eastern coal, 24% Midwestern, 45 — 50% lignites) are (1) by the admixture of fuel already dried in the mill with the raw feed and (2) by the use of high temperature air. The C-E Raymond Bowl Mill was designed to do both of those things, and does them well. Air temperatures of 700° F. and above can be utilized.**

LOW POWER CONSUMPTION — **Basic design characteristics of the Bowl Mill permit pulverizing at less power per ton of material than any mill now available. The rapid flow of material through the mill and the prompt removal of fine coal as it is produced prevents over-grinding. This, in conjunction with the relatively low mass of grinding elements and rapid drying action in the mill, assures minimum power consumption.**

RELIABILITY — **Design and materials are responsible . . . but results prove the point — such results for example as operating records of 8500, 10,000, 15,000, 20,000 continuous service hours without repair or replacement of parts.**

MAINTENANCE — **Bowl Mill maintenance cost has always been the lowest in the field. Continuing improvements in designs, materials and construction keep it that way. A minimum of outage time is required for dismantling and assembly. It's a matter of record in many plants that higher costs of material and labor over the past 15 years have not been reflected in increased maintenance cost per ton of coal pulverized.**

FINENESS CONTROL — **All necessary adjustments to control fineness of finished product can be made conveniently from the outside of the pulverizer *while it is in operation.***

AUTOMATIC GRINDING PRESSURE — **The arrangement of spring-loaded roller journals on the Bowl Mill provides automatic compensation for the variation in pressure between grinding surfaces required by variation in grindability of coals.**

LUBRICATION — **Is no problem with the Bowl Mill. When required — at infrequent intervals — all lubrication is handled from outside the mill while it is in service.**

VIBRATIONLESS — QUIET — **The Bowl Mill's grinding rollers make no metal-to-metal contact with the grinding ring, assuring quiet, vibrationless operation.**

• • •

Whether you are evaluating pulverizers for your present plant expansion program or for future requirements, we suggest you use the above check list to get the facts. Send for Catalog PC-8 for further details.

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There are many other advantages built into the 9VGR. There is a Multiclone representative near you who will be glad to supply complete details. Or write direct, asking for your free copy of Bulletin #M209 which contains full details.

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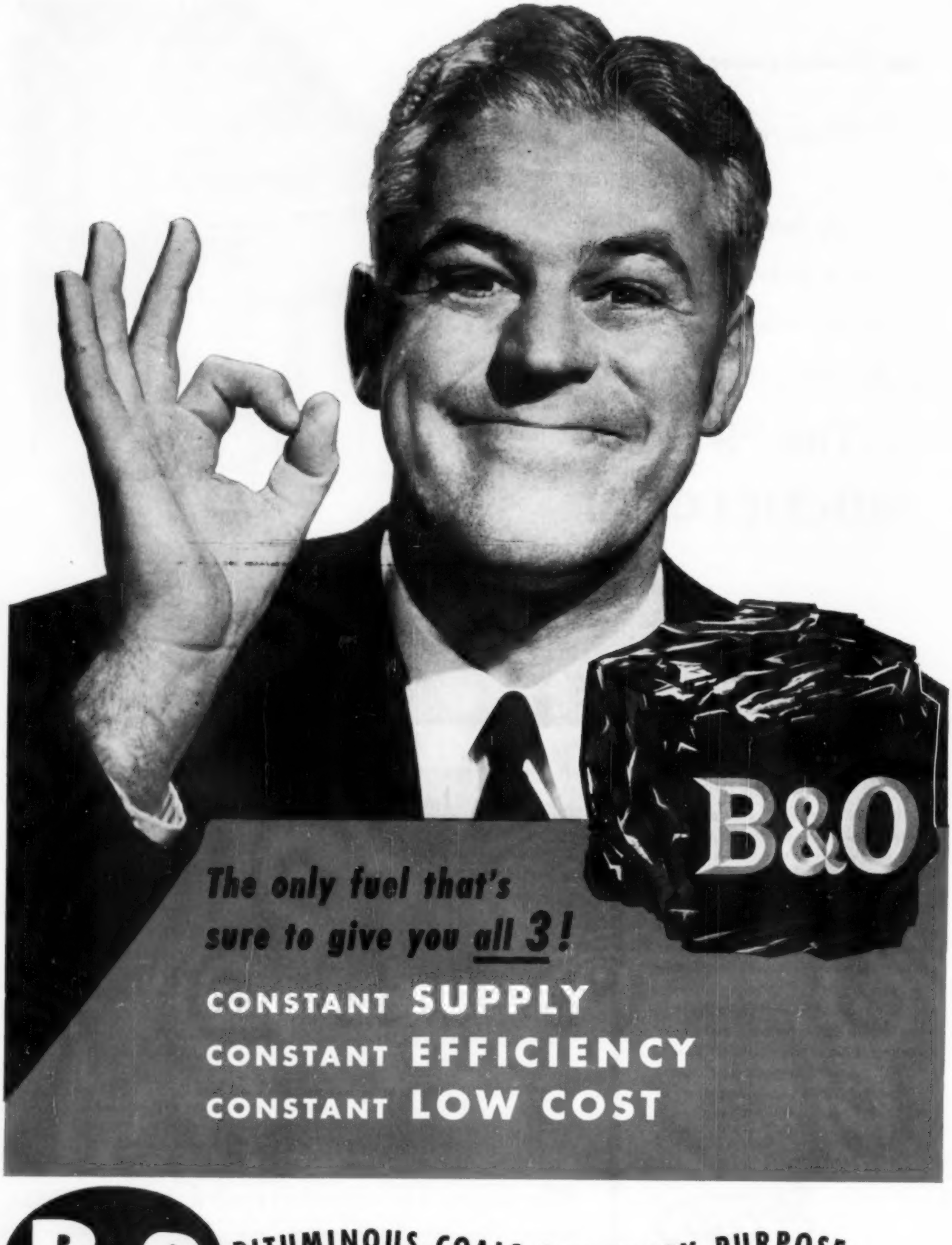
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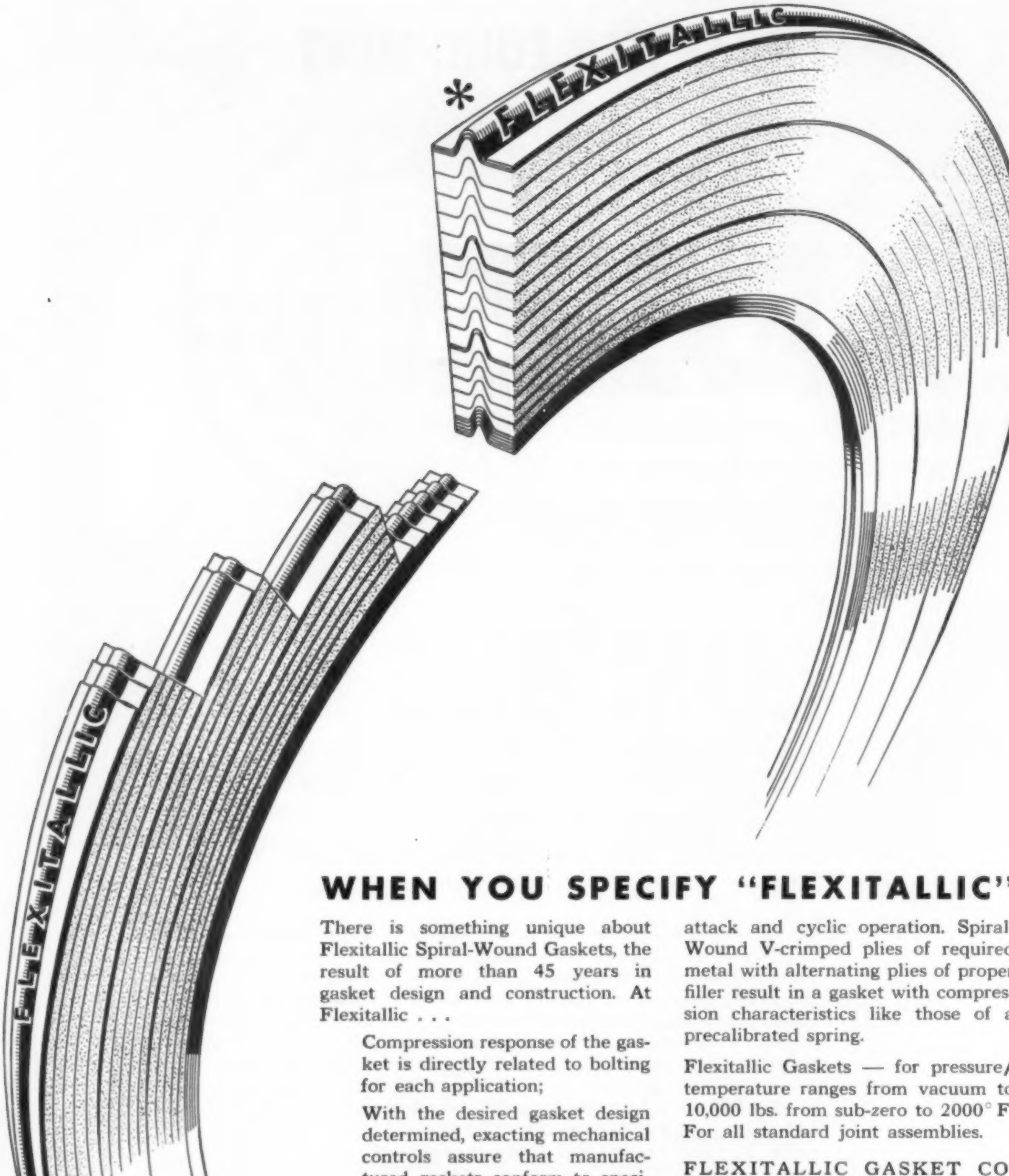
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FLEXITALLIC

COMBUSTION

Editorial

Heat, Man and Utility Services

New York City, at the time of this writing, has been suffering the effects of the first heat wave of the season. *The New York Times* in its Wednesday, June 19, issue, stated that the city had set a record for use of electricity as desperate residents sought every form of artificial cooling in a sweltering 92 F heat.

Consolidated Edison Co. serving the five boroughs of New York City plus Westchester reported a peak of 3,401,000 kw between 1:00 and 2:00 p.m., June 18. This compared with the record of 3,283,000 kw on a frigid 3.1 F day last January 15, and the previous summer record of 3,203,000 kw, June 27, 1956. (The very day this June 18 peak record was reported it was broken, June 19, when the demand hit 3,422,000 kw.) To our knowledge this is the first time the summer peak exceeded the winter one in the New York City area. We feel it presages things to come.

Con Edison, however, had its problems compounded on the preceding day, Monday, June 17, when the demand approached the previous peak record. The company has a working arrangement with Niagara Mohawk Power, Long Island Lighting Co., Central Hudson Gas and Electric and Rockland Light and Power to give it in effect an available capacity of 4,000,000 kw, for a margin of about 14 per cent above even this new peak. At the very hour of need, Monday, June 17, the chain of circumstances all operating men worry about, occurred. Certain of the tie-line partners were deep in troubles of their own. Before Con Edison could activate its off-the-line equipment and pick up the load it had had to inflict brief shutdowns upon certain of its Brooklyn and Bronx subscribers.

In our opinion Con Edison performed a masterful job of public relations. It told its story on TV, the radio and to the press. It pointed out such fundamentals as that electricity cannot be stored in quantities useful for supplying a city, that it takes up to six years to build and install a kilowatt of capacity and hence that Con Edison has in force a planning section constantly keeping tabs on population and use trends to keep ahead of load growth. Further, like prudent insurance companies, Con Edison reported that it spreads its risk of sudden demand surges through tie line connections with neighboring utilities. By this means it very effectively and quickly scotched the thought that the limit had been reached for air conditioning and refrigeration devices. We think the industry can profit from the example of an alert operating company capable of safeguarding its reputation and fast-moving enough to do the job effectively and, we think, most satisfactorily.

Mechanical Brains

A fast-growing fact of life for utility management today is the arrival on their properties of mechanical brains in the form of electronic computing devices. We are grateful to G. L. Way, assistant manager of engineering for the Bechtel Corp., for some illuminating statistics he compiled on these devices and some sage comments he advanced on their applications before the semi-annual meeting of the ASME in San Francisco, June 9–13.

From a survey of 150 of the major utilities representing about 73 per cent of the total U. S. generating capacity, Mr. Way received replies from 101 firms. The reporting firms indicated the punch-card equipment so familiar in accounting operations seems to have essentially saturated its market. Analog and digital equipment, however, face a different future. Of the 28 analog installations, 13, or about half, are over five years old. With the exception of two Federal government utilities all these 13 are in the largest capacity group. There are no digital installations over three years old reported, and 16 of the current 23 are less than a year old or not yet installed.

The state of the art in correct application of these computer aids is progressing well. Industry and the engineering societies have combined to present case histories of application experiences and to further the dissemination of the ideas and knowledge arising from these early applications. Yet in the last analysis, as Mr. Way so ably states, the machines are only as good as the information fed to them. The competent scientist and engineer still must play the major rôle. He it is who must express engineering applications in complex equations which in turn can be converted into forms which the computer can handle. And so we come up to the inescapable conclusion that the mechanical brains will force industry to seek out more and better trained engineers.

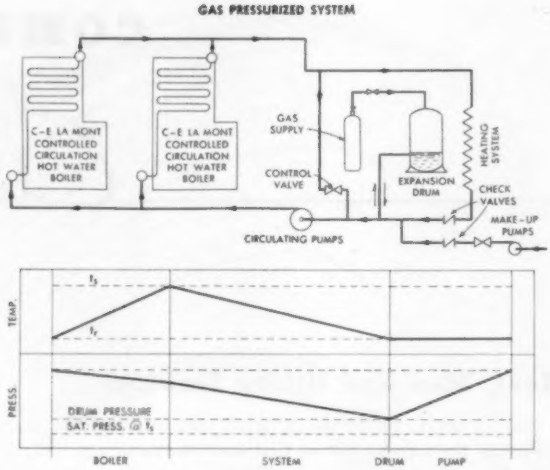


Fig. 1—Gas pressurized systems diagrammed above establish pressure temperature relationships at various system points as plotted in the graph

System requirements, in the author's opinion, determine the choice of high temperature water or steam for heating and process needs. For large heating systems and certain process applications high temperature water frequently has the advantage. Today boilers are available designed specifically for high temperature water service, and standardized to reduce costs.

By S. F. MUMFORD[1]

Combustion Engineering, Inc.

Controlled Circulation Boilers for

HIGH temperature water systems are closed systems. Makeup is required only to restore the amount of water that leaks out of the system at valve stems, pump shafts and similar packed joints. Obviously the average water temperature in the system will vary within limits, depending on the load, and as a result an expansion drum is used to permit expansion or contraction of the water volume as a result of change in average water temperature.

To maintain pressure in the system two methods have been used, steam pressurization and gas pressurization. Gas pressurization is commonly called mechanical pressurization. Gas identifies the type of fluid used for pressurization, whereas mechanical indicates a method used to pressurize the fluid.

In the steam pressurized system, steam is permitted to form in the upper portion of the expansion drum. The fuel firing rate of all operating boilers is controlled by pressure in this common drum. If pressure tends to fall below the set pressure fuel firing of all operating boilers is equally increased, and conversely, if pressure tends to increase above the set value a similar reduction occurs. The small amount of makeup required to hold water level in the expansion drum within predetermined limits is added intermittently and automatically by a small makeup pump.

In the gas or mechanical pressurized system a pressure is maintained above the water level in the expansion drum using air, or more recently, nitrogen. This pressure is maintained independent of the heating load by means of suitable controls which add or bleed off the gas as changes in water level occur. Firing of each boiler is controlled by the water temperature leaving the boiler.

Gas Pressurized System

Although the physical layout and size of individual installations varies, the basic components and usually the basic arrangement of the systems are similar. A typical diagrammatic arrangement of a gas pressurized system is shown in Fig. 1 with the graphs at the bottom indicating the pressure-temperature relationship at various points in the system. Return water, t_r is heated in the boiler and delivered to the system at supply temperature, t_s. The water gives up its heat to the system load which is usually divided in several zones and is returned to the suction of the circulating pump at t_r. The circulating pumps are selected with sufficient head to overcome both the system and boiler resistances. Pressure higher than saturation pressure corresponding to the boiler outlet temperature is maintained in the system by means of gas pressure superimposed on the system at the expansion tank. The expansion tank floats on the line. Water temperature at the boiler outlet is used as an index for combustion control.

Steam Pressurized System

The basic steam pressurized system is shown diagrammatically in Fig. 2 with a similar graph to indicate pressure-temperature relationship throughout the system. Water at return temperature, t_r is heated in the boiler and delivered to the expansion drum at supply temperature, t_s which is essentially equal to saturation temperature corresponding to operating pressure in the expansion drum. The circulating pumps taking suction from the drum circulate the hot water through the system. The water gives up its heat to the load and is returned to the boilers at temperature t_r. The circulating pumps are selected for sufficient head to overcome both the system and boiler resistances.

For each of these systems a bypass around the heating

* Presented at Annual Meeting of National District Heating Association in Hot Springs, Virginia, June 5, 1957.
[1] Chief Engineer, Hot Water Boiler Div.

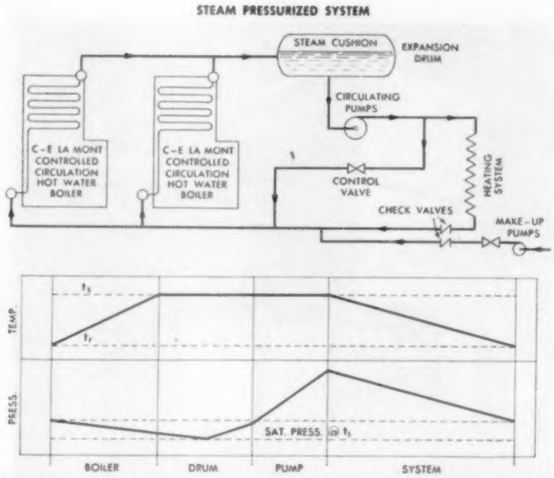


Fig. 2—Basic steam pressurized system is depicted for contrast with Fig. 1 and system relationships have been plotted for reference

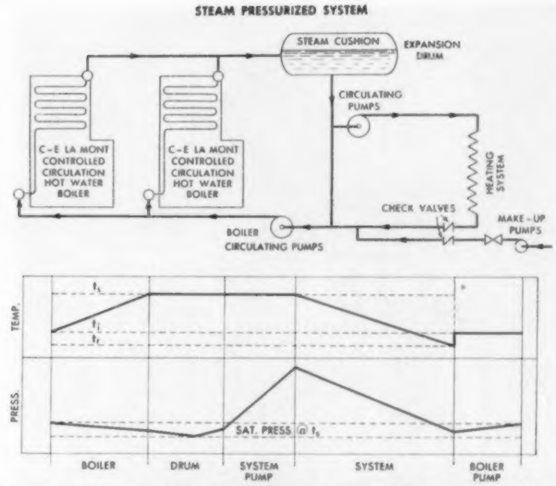


Fig. 3—Variation of basic steam pressurized system employs two pumps, one for the heat distribution system and a second for the boiler cycle

High Temperature Water Heating*

load is provided. During initial start up it may be desirable to completely bypass the system. For partial load operation, especially when several heating zones are not operative, it may be desirable to bypass a portion of the total water circulated through the boilers, in which case the temperature of the water entering the boilers would be between the normal return and supply temperatures.

Although not shown in Fig. 1 and Fig. 2, a line to bypass the boilers is usually provided for low load operation with only one of several boilers in use.

A variation of this basic steam pressurized system is shown in Fig. 3. In this system two groups of pumps are used; one group to pump the water through the heat distribution system and the other to pump the water through the boiler and associated piping. This has been used because some consulting engineers feel it provides greater system flexibility or because some types of boilers which have been used have a high waterside pressure drop. Boilers designed specifically for high temperature water should have a low waterside pressure drop permitting use of standard single stage pumps which have sufficient head to overcome the resistance of the heat distribution system and the boilers.

In this system, return water at temperature t_r is heated in the boiler and delivered to the expansion drum at the supply temperature which is essentially equal to saturation temperature corresponding to the operation pressure in the drum. The system circulating pumps which take suction from the drum circulate the hot water through the system where it gives up its heat to the load and is returned to the boiler house where it mixes with water from the drum and enters the suction of the boiler circulating pump. The system pumps are selected for the head loss through the heating system only and the boiler circulating pumps are selected for the head loss through the boiler and associated piping. Pres-

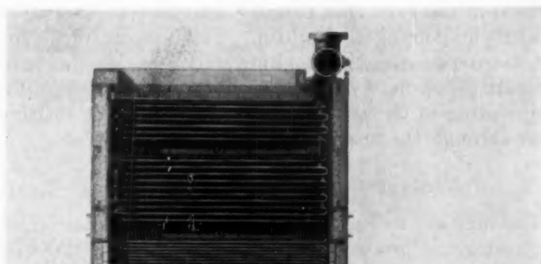
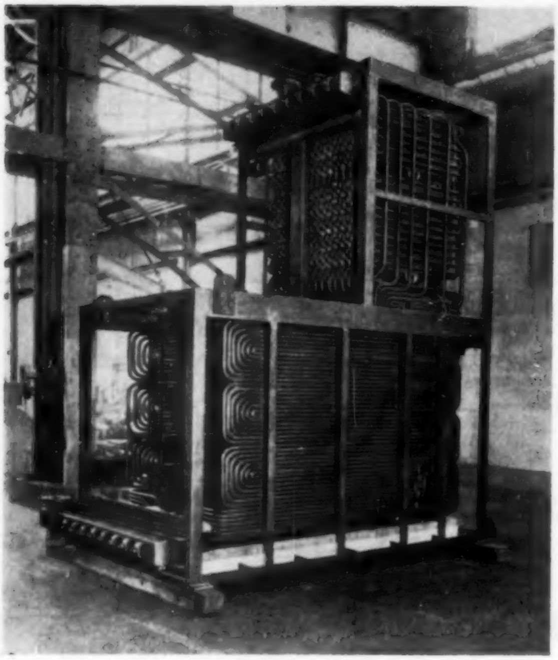


Fig. 4—Sectional view of a boiler designed for oil or gas firing. Air cooled furnace floor provides for alternate arrangement with a stoker



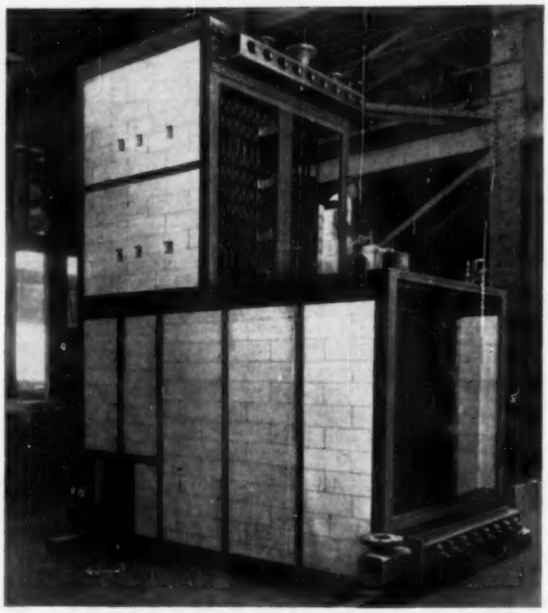


Fig. 5, left, 6, above—a 12,000,000 Btu per hr boiler

sure in the system is maintained by means of a steam cushion in the expansion drum. This pressure is used as an index for combustion control. The temperature of the water entering the boilers, indicated as t_i on the temperature graph may vary between the supply and return temperature of the system, depending upon the relative flows through the heating system and boilers.

High Temperature Water vs. Steam

The decision to use high temperature water or steam for heating or process work will depend upon the size, arrangement and type of load.

A steam heating system requires greater net plant output because of the losses associated with the change of phase of the heating medium, i.e., steam to condensate. These losses which are primarily trap and vent losses or flash off from condensate can account for 10–25 per cent of the net plant output. Since high temperature water exists as a liquid throughout the system, these losses do not occur and as a result the required capacity of hot water boilers is less than steam boilers for a given system output.

Maintenance costs for high temperature water systems are less because of the elimination of high maintenance items such as steam traps, pressure reducing valves, condensate equipment.

Since makeup for a high temperature water system is negligible, blowoff is unnecessary with normal operation. Makeup equipment can be very simple and inexpensive, usually consisting of a small water softener, a pair of makeup pumps and provision for intermittent addition of chemicals to the heating system.

Generally high temperature water distributing lines, both supply and return, are of the same diameter, being smaller than the steam distributing mains and larger than the condensate return lines. Piping cost of the two systems will depend on the actual distribution system, with high temperature water piping costs becoming relatively less with larger systems or longer distribution lines. Underground high temperature water lines can follow ground contours, thus simplifying piping design.

Plant engineers are familiar with the problem of corrosion in the condensate lines of a steam system. In the closed high temperature water system oxygen is eliminated on initial operation and therefore this problem of pipe corrosion and replacement does not exist.

For heat consumers such as unit heaters, radiant panels and coils of absorption refrigeration equipment, high temperature water may be used directly. As with steam, it is used indirectly for domestic hot water. Low pressure steam or low pressure hot water, if required, may be produced in suitable exchangers.

A high temperature water system has substantially greater heat storage capacity than a steam system. As a result, fluctuating loads in the system tend to be damped out so that they do not directly or immediately affect boiler loads. The boilers therefore operate at a more constant rate which improves their operating efficiency and the efficiency of the heating system as well.

Because of the heat storage capacity the heating system acts as an accumulator, permitting extremely close control of temperature and the ability to readily meet infrequent peak loads. Close control of temperature is often of considerable importance in process equipment, resulting in improved product quality or increased production. The ability to meet infrequent peak loads may allow the installed capacity of the heating system to be reduced.

Generally the installed cost of a steam system will be less in smaller capacities with high temperature water systems showing up better in the larger capacities. As high temperature water installations increase and additional experience is gained, some initial complications frequently identified with any new development will be eliminated, thereby reducing first costs. Furthermore, since the boilers are the largest single item of equipment

Fig. 7—Completely assembled boiler Figs. 5, 6 on trailer truck

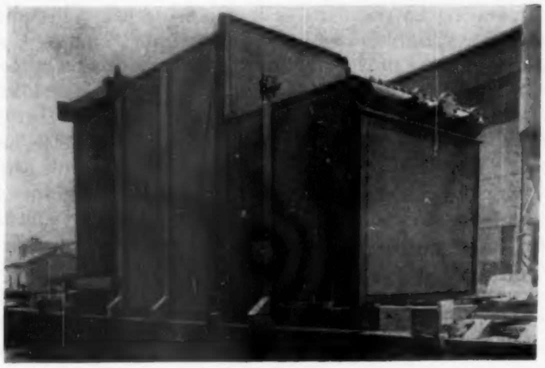


Fig. 9—Shop-assembled 30,000,000 Btu per hr unit on flat car

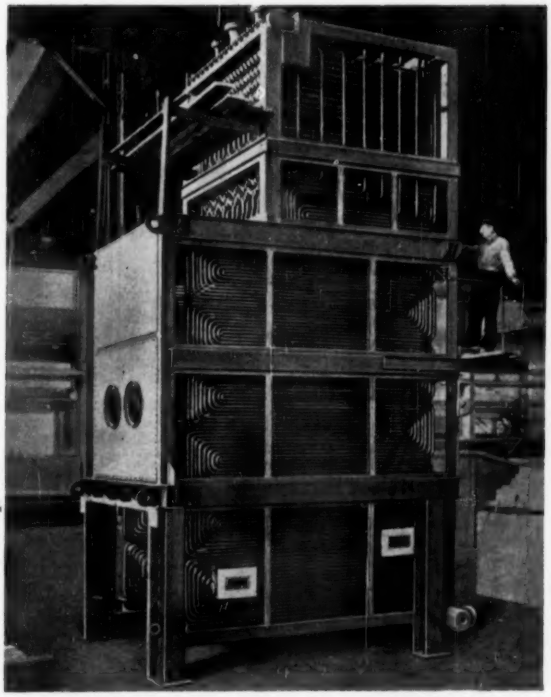


Fig. 8—The intermediate group of hot water boilers compared to those of small capacity such as Fig. 5-7 employ the same circuit designs and have the same construction features. The unit above, a 30,000,000 Btu per hr installation for stoker firing, is provided with lugs for lifting and turning the boiler which is shipped on its back, Fig. 9

cost in the Boiler House, standardization of hot water boilers to the same degree that small steam boilers are presently standardized should tend to reduce any cost differentials in the smaller capacity plants.

Controlled Circulation Hot Water Boilers

In some initial or smaller high temperature water installations steam boilers have been used to heat water. Usually an attempt is made by internal baffling to distribute water flow within a boiler and by external connecting pipes to balance conditions between boilers. Obviously such applications are a compromise since boilers are available which are designed specifically for high pressure hot water service.

The circulating pumps provide positive circulation throughout the heating system. The use of controlled circulation boilers extends this desirable feature to each tube of the boiler unit. This is accomplished by orifices located at the entrance of each tube circuit. Water is distributed to each circuit in accordance with the heat absorbing capacity of the circuit. Screens are installed to protect each orifice. Although holes in the screen are of smaller diameter than the orifice the total open area is considerably greater. This positive arrangement not only meters the water to each tube circuit but also assures proper distribution within a boiler and, with boilers operating in parallel, assures equal flow distribution between boilers.

With accurate control of water flow there is considerable design flexibility. Water velocities are maintained to provide maximum cooling of tube circuits and to avoid deposition of any undissolved solids with minimum pressure loss. Even with large units the total boiler pressure loss does not exceed 10 psi.

As shown in Fig. 4, the water heating circuits of the boiler are designed for continuous, upward, once-through flow from the inlet headers at the bottom to the outlet header at the top. Vapor binding will not occur under any operating condition since all tube circuits are vented to the outlet header. All circuits are drainable. Headers are accessible from the outside of the boiler casing.

There are no baffles in the boiler. Parallel flow of gas and water assures moderate tube metal temperatures in zones of low gas temperature, minimizing the possibility of corrosion resulting from high sulfur fuels.

The symmetrical arrangement of the heating surfaces permits a simple, rugged, gas tight casing construction. Casings are made up of relatively large rectangular plates welded to a frame of standard structural angle or channel shapes. The resulting box beam structure encloses and supports refractory and insulation and pressure parts. Tube circuits are attached to casing structurals with adequate provision for differential expansion. This type of casing construction is suitable for pressure firing and provides the extremely rigid structure which is necessary for handling, shipping and installing partially or completely assembled boilers.

Extensive use of water cooled surface not only minimizes furnace maintenance but also assures cool casings and low radiation losses. The gas temperature leaving a

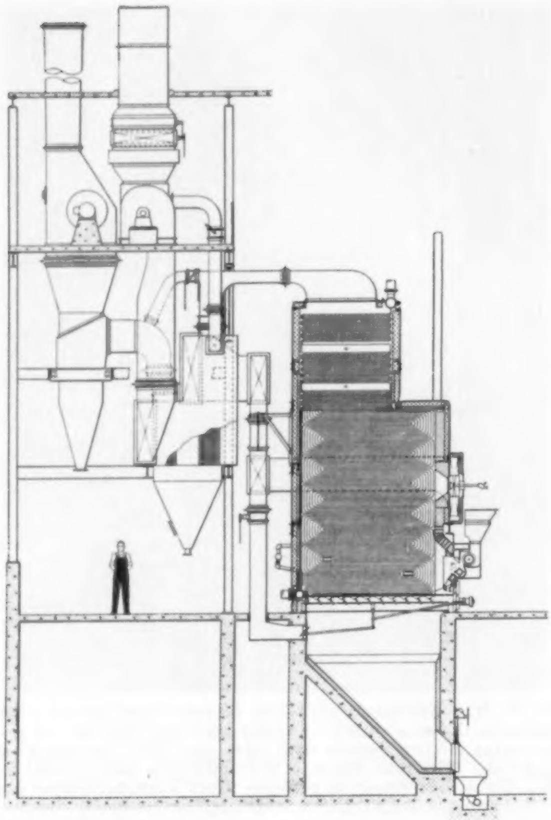


Fig. 10—Unit in Fig. 8 appears as shown in an actual installation. Note equipment for stoker firing

furnace is a function of the amount of radiant absorbing surface in the furnace, not the volume. Therefore extensive use of water cooled surface, as shown in Fig. 4 and other figures as well, allows a very compact furnace with moderate furnace temperatures. In specifying or requesting performance conditions, the furnace release or absorption rate in Btu per square foot of eprs (effective projected radiant surface) is the important criteria in judging furnace conditions, not the release rate per cubic foot of furnace volume.

In the event the water flow through a boiler drops below a predetermined safe value, protection of tube circuits is assured by a safety device which shuts off the supply of fuel and combustion air. With gaseous or liquid fuel the fire is extinguished immediately but with stoker firing there remains some residual heat in the fuel bed. It is therefore important to use a stoker that operates with a very thin fuel bed, such as a spreader stoker. With spreader stoker firing, either stationary dump grates or an alternate arrangement of moving grates are used for capacities up to 50 million Btu/hr and traveling grates for larger sizes. To obtain a wide operating range and maintain good combustion conditions at the low end of the range the stokers are selected for grate heat release rates at the design condition of 500,000 Btu/hr-sq ft for dumping grates and 650,000 Btu/hr-sq ft for traveling grates.

Similarly the low end of the operating range should be considered in selecting forced and induced draft fans. Fans should be adequate for the design condition but the addition of substantial tolerances may result in a fan that is too large for good control of flows at minimum rates. This is especially important in heating.

Standard Designs

Standard boilers to meet usual requirements are available. In the small sizes they are completely shop assembled and in the large sizes shipped as component assemblies. The use of standardized equipment has many advantages. Manufacturer's engineering and fabrication time and costs are reduced, resulting in lower prices and shorter delivery. The use of standard and proven design and construction details results in lower operating and maintenance costs. Partial or complete shop assembly reduces field erection costs.

In setting up standard designs it is necessary to consider the variables involved. For normal heating applications most of the significant variables except capacity fall within a limited range. Capacities of individual boilers have varied from below 10 million Btu/hr to above 100 million Btu/hr. Large units in the 200–300 million Btu/hr range are entirely feasible but at this time have not been considered as part of the standard range.

Based on an analysis of inquiries for hot water boilers, design considerations and shipping clearances, three size groups were selected: a small group covering units in the capacity range of 8–25 million Btu/hr, an intermediate group covering the range of 25–50 million Btu/hr, and a large group covering a range of 50–120 million Btu/hr. These nominal capacities are for oil or gas fired units. For stoker firing the boilers in these groups are essentially the same except that the furnace is generally higher.

The furnace of a stoker fired boiler is arranged for sufficient grate area and for adequate distance for flame travel to the relatively cold convection surface. This results in a furnace considerably larger than one designed for oil or gas. To prevent slagging, ample water cooled surface is provided in the furnace to reduce the gas temperature below the softening temperature of the ash.

Figs. 5 through 7 show a 12 million Btu/hr oil fired unit in two stages of erection and in final transit. This is typical of standard boilers in the small capacity group. Fig. 5 shows the tube circuits which have been rolled into the inlet and outlet headers, installed in the supporting casing frame. The refractory floor is installed prior to erecting the pressure parts. Fig. 6 shows the same unit with sidewall refractory and insulation in place. Side casing panels in three sections will subsequently be attached to the steel framework by seam welding at the edges and plug welding intermediately. Lugs for lifting the boilers are provided. Shipment is in an upright position. Fig. 7 shows the unit being loaded on the trailer truck. This is a completely assembled unit with all refractory and insulation in place, and in this case, with the package burner as part of the assembly. Soot blowers are installed and piped up. Only items of trim such as valves, which might be damaged in shipment, are omitted from the assembled package.

Figs. 8 and 9 are a stoker fired unit for 30 million Btu/hr. This is typical of boilers in the intermediate capacity group. It will be noted from Figs. 8 and 9 that although the physical size is considerably greater the construction details are the same as for the smaller units. For stoker firing the water cooled floor is omitted,

the tube circuits being fed from the inlet header at the rear. Although the front casing is installed, the refractory of the front wall and the burning equipment is omitted for shipment. The refractory front wall is subsequently installed in the field from inside the furnace. All other refractory and insulating materials are installed behind the water cooled walls prior to shipment. Lugs are provided to lift and turn the boiler which is shipped on its back, as shown in Fig. 9. These lugs are also used for securing the boiler to the flat car. Supports are designed so that refractory and the pressure parts will be adequately supported when the unit is in a vertical and horizontal position. The openings at the gas outlet, floor and part of the front wall are closed with light gage steel plates to protect the unit during shipment.

A sectional elevation of the boiler arranged in the boiler house is shown in Fig. 10. Air from the forced draft fan at the upper level passes through the vertical tubular air heater and thence by ducts to either the stoker or oil burners. Flue gas leaving the boiler passes through the gas side of the air heater through a dust collector and then to the Thermix stack. Although an air heater usually cannot be justified for heating applications it was used in this case to improve combustion of the specified lignite fuel.

The boiler shown in Fig. 4 is typical of higher capacity units. The arrangement is generally similar to the lower capacity units. This particular unit is suitable for possible future installation of a stoker. For initial operation with oil a refractory floor is cooled by combustion air.

Boilers in this capacity range are shipped in component assemblies, the convection bank, the side walls in one or two pieces, and the rear wall. Pressure parts are attached to the structural members and in the case of the rear wall and convection bank components, the terminal tube ends are rolled into the headers. The casing plates are tack welded to structural members forming a rigid shipping frame. After erection of these assemblies in the field, the casing plates are removed for installation of the insulation and refractory.

Although standard boilers are suitable for many installations they obviously are not universally applicable. The inherent design flexibility of the controlled circulation boiler allows the use of standard components and details even though the physical size of arrangements is markedly changed to meet specific requirements. This

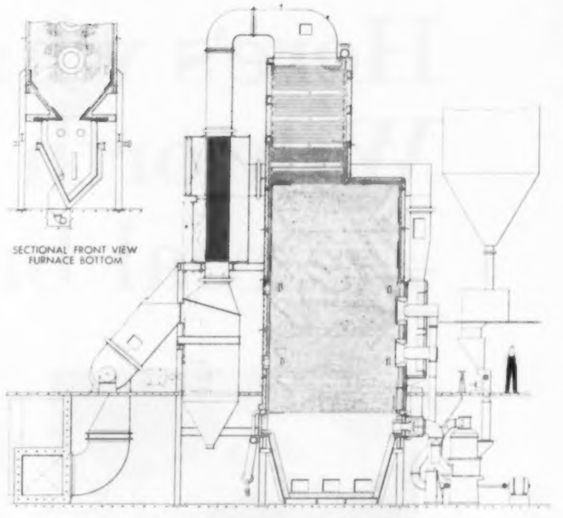


Fig. 13—Arrangement of 70,000,000 Btu per hour pulverized coal fired hot water boilers.

Fig. 11—Above view is of a 70,000,000 Btu per hr pulverized coal fired hot water boiler

characteristic is illustrated by Fig. 11 which shows one of three pulverized coal fired hot water boilers installed in a Canadian Army Camp. The furnace size and shape including the hopper bottom are designed specifically for the efficient combustion of high ash, high sulphur, Minto bituminous coal, yet the basic arrangement of the furnace water cooling, convection heating surface and casing structure are retained.

Conclusions

The decision to use high temperature water or steam for heating or process work depends on system requirements. For large heating system and certain process applications, high temperature water frequently has advantages over steam.

Boilers are available which are designed specifically for high temperature water service. These boilers have been standardized over a wide capacity range to reduce first costs. Operating cost and maintenance expense are also reduced by proven design and construction features of these standard controlled circulation boilers.

First Welded Tube Condenser Being Installed at the Dayton Power & Light Co.

The operator on the cover photo is automatically welding one of the 11,500 tubes in a new 90,000 sq ft Allis-Chalmers condenser installed at the Frank M. Tait plant of the Dayton Power & Light Company. This is the first large condenser to use welded tubes. The condenser will serve Unit 4, a 125,000 kw turbine generator fed from a once-through boiler steam cycle.

Once-through boilers and supercritical steam cycles and nuclear power plants will demand more positive means of sealing tubes and sheets to insure against the possibility of condensate contamination.

Intensive research at Allis-Chalmers has been carried on over the last several years to determine the compatibility of different tube and tube-sheet materials and to perfect the design of a completely automatic welding gun. The results of this research are practical and permit economical welding of a wide variety of tubes and sheets.

The welding operation has been simplified to the point where the operator needs only position the gun and press the trigger—the actual welding then is automatically timed and complete uniformity is achieved. The tube sheets are specially prepared where welding is to be used.

As the need for more positive sealing of tubes and sheets becomes increasingly important, it is expected that welding will supplant rolling in many condenser applications.

At present Allis-Chalmers has eight large condensers on order that call for welded tubes—including a duplicate 90,000 sq-ft condenser for the Dayton Power & Light Co.

By C. E. BEAVER*

Research-Cottrell, Inc.

Automation—The Key To More Efficient Dust Collection

ECONOMICAL industrial processing and good community relations demand that gas cleaning systems operate at their optimum levels of collection efficiency. Manufacturers and users of dust collectors have cooperated in improving both operating techniques and equipment design to achieve these twin goals. Investigation and operating experience identified the major key to obtaining maximum round-the-clock collection efficiency in any particular installation as the *constant* maintenance of a proper balance between load characteristics and power input to the precipitator. This fact has been known for quite awhile. Attaining this desirable condition, however, was not possible until the application of continuously acting electronic feedback circuitry to monitor precipitator operation.

Establishing Proper Balance

A characteristic of electrostatic precipitators is that collection efficiency is critically dependent upon maintaining across the electrodes the maximum voltage and current necessary to sustain the optimum sparking rate. The optimum rate of sparking is considered as the rate which accompanies maximum collection efficiency in most precipitators. While the sparking in itself lowers efficiency, the high voltage and current at which optimum sparking occurs more than offsets loss from the sparking, with the net gain in efficiency. If we lower voltage and current below the point of optimum sparking, there is a net loss in efficiency. If we raise voltage and current above this point, the resultant increased sparking would cause a net loss in efficiency.

The sparking rate thus serves as an index showing whether voltage and current are too high or low. For most precipitators, the optimum sparking rate lies between 50 and 100 sparks per minute. This relationship is illustrated by Figs. 1 and 2, which show the connection between efficiency and sparking rate for one section of a precipitator, and sparking rate and peak voltage in typical fly ash precipitators.

Unfortunately this seemingly simple relationship is complicated by several factors. Precipitator conditions, such as temperature, flow rate, composition, and humidity of the gas being treated, and size and resistivity of the particles being removed, change constantly from one moment of operation to the next. And these conditions determine the optimum voltage and current, the so-called "ideal electrical power," necessary to maintain the desired sparking rate.

Fig. 3 shows this relationship graphically by plotting "ideal electrical power" against time and showing how this optimum power input varies from one minute to the next.

Need for Automation

Therefore, in order for a precipitator to operate continuously at maximum round-the-clock collecting efficiency, it is necessary to have an expert hand at the controls constantly, correcting power input whenever necessary to maintain the desired sparking rate for the installation. A newly developed electronic feedback control, the Cottrell Automation System, provides

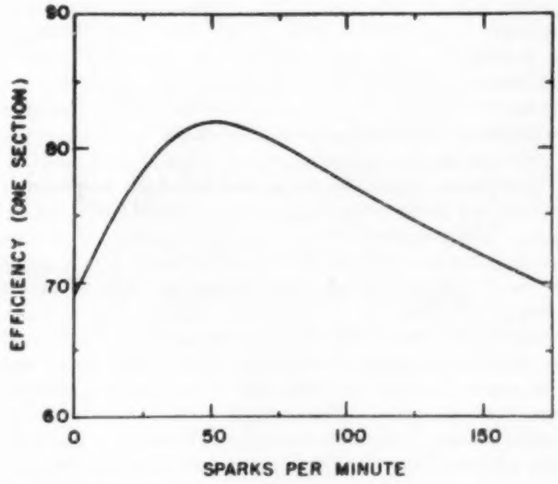


Fig. 1—Percent efficiency as a function of average sparking rate for a typical fly ash precipitator appears above

* Vice President.

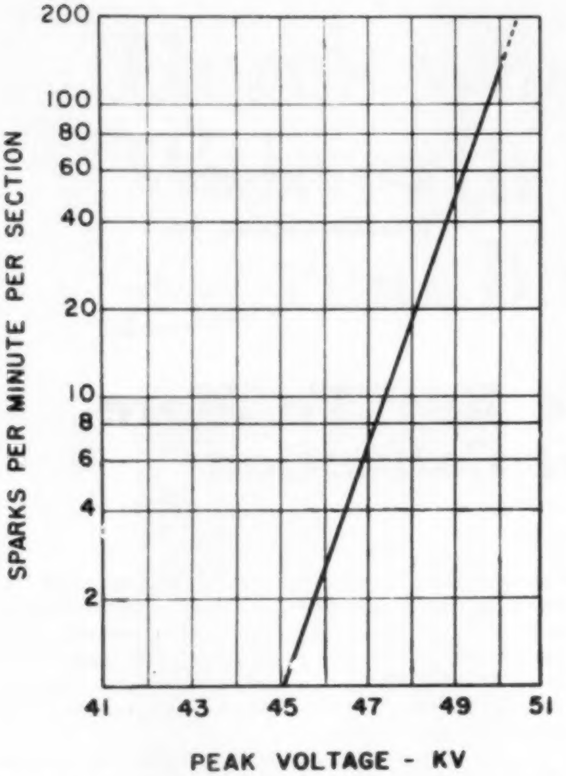


Fig. 2—Variation in sparking rate with operating peak voltage for a representative fly ash precipitator gives a curve like this

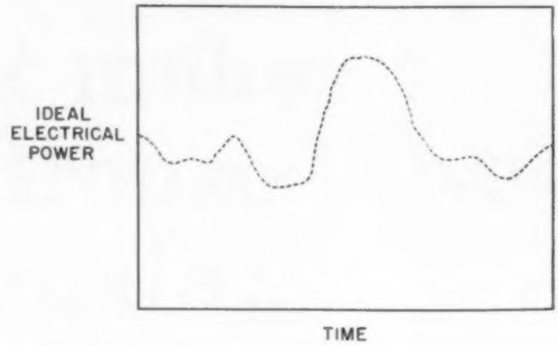


Fig. 3—Conditions such as temperature, humidity, flow rate affect ideal electric power at a given moment. Above curve shows a typical operating curve

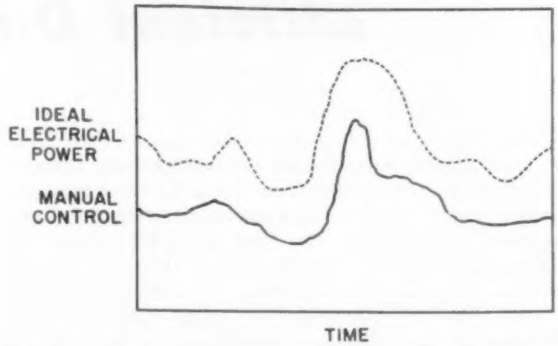


Fig. 4—Operating men in attempting to arbitrarily balance off conditions referred to in Fig. 3 will hedge on adjustments so manual tends to fall short of ideal as shown here

the required continuously monitoring hand, eliminating the need for manual supervision.

Without the CA System, adjustment of each electrical set in a precipitator installation must be made manually by an operator at a control panel. This requires for maximum collection efficiency and economy the supervision of an expert, experienced operator controlling numerous knobs, meters, and panels. In some installations, for instance, as many as twelve or more electrical sets may have to be manually adjusted and interrelated 24 hours a day by operators. Yet, even with this type of continuous manual supervision, Research-Cottrell has discovered that it is virtually impossible for an operator to detect changes and make the required manual adjustments fast enough to keep pace with changing conditions in the precipitator.

Most plant operators recognize this fact and accommodate for it by adopting a sort of compromise operation. When faced with changing conditions in the precipitator and in the gas being cleaned, which occur in most normal installations, operators will set their manual controls at a moderate power input level, considerably lower than the one required or anticipated for maximum round-the-clock collection efficiency, and also lower than the power level for which the electrical sets were designed. This compromise power level obviates the need for continuous supervision and prevents over-current tripouts that might result if the power input were set at the higher level required at the time of adjustment. Fig. 4 demonstrates this type of operation at moderate power input levels by a part-time operator by showing the difference between "ideal electrical power" and the actual manually controlled power input.

Performance Checks on Automation

Field tests have demonstrated that with the CA System, which constantly monitors and adjusts power input in accordance with the conditions existing in the precipitator at each moment of operation, power input more closely approximates this "ideal electrical power" that goes hand in hand with maximum round-the-clock collection efficiency. The system thus enables higher utilization of the electrical equipment capacity. Also, rectifier power conversion efficiency at full load is approximately 80 per cent as against 40- to-50-per cent for conventional sets.

Fig. 6 compares actual metering charts of current and voltage inputs to a precipitator section of a fly ash collector. These charts show that power input increases about 65 per cent with the CA System, from 5.6 kw with manual control to 9.3 kw with automation control.

The CA System controls precipitator power input for the three most common operating conditions. These are conditions in the precipitator under which the current may be limited, the voltage may be limited, or the sparking rate may be limited. There are a number of operating factors that contribute to the existence of any of these conditions.

For example, in the case where there is low precipitator impedance, input is characterized by high current, low

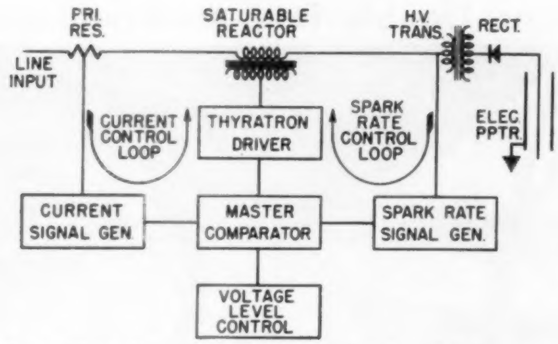


Fig. 5—Block diagram for CA system developed by Research-Cottrell pictures major elements involved

voltage, and little or no sparking. In such a case maximum current should be provided within the rated capacity of the electrical equipment. On the other hand, precipitator impedance may be very high, shown by low current, high voltage and, again, little or no sparking. In this case the maximum voltage should be provided within the capacity of the electrical equipment. Finally, precipitator operation may be characterized by sparking taking place well below the current and voltage limits employed in the first two examples. In this case, optimum performance is maintained by establishing a reasonably constant sparking rate, about 100 sparks per minute.

The basic operation of the CA System is shown in the block diagram of Fig. 5. The two feedback loops, shown by the arrows, operate either independently or cooperatively, as the situation warrants. One loop monitors current and the other sparking rate. The current control is extremely sensitive and permits full rated rectifier operation with complete stability. Sparking rates are easily preset, in accordance with experimental observations with the particular installation, to any value between 0 and 500 sparks per minute.

A single control switch actuates the starting circuits of all the rectifier sets for the precipitator installation. The automation system for each set then automatically adjusts and maintains power input to the precipitator at the point of best performance. An a-c current is fed into the saturable reactor that serves as the control element. This static control element varies input to the high voltage rectifier by functioning as a variable series impedance through adjustment of a d-c current flow in its core control winding. This d-c control current is supplied by the thyratron driver, whose output, in turn, is controlled by the current and sparking rate servo loops and the voltage level control.

A spark signal, taken from the high voltage transformer primary, is converted to a low level d-c signal. This signal is proportional to the average sparking rate in the precipitator. It is used to produce an error signal by comparing it with a preset reference voltage indicative of the ideal sparking rate.

The current signal consists of a second low level d-c signal proportional to the average current flowing in the high voltage transformer primary circuit. This signal, obtained from a low-ohmage resistor placed in the primary circuit, is compared with another preset reference voltage to produce an error signal.

The voltage level control, shown in the block diagram, provides an upward bias to raise the rectifier transformer voltage to its rated value. The three references are added together in the master comparator, which acts as a mixer to provide an output signal that is applied to the grid driver. The grid driver provides the phase-shifted trigger pulse to fire the thyratron. The angle of the phase shift, which depends on the amount of total error signal supplied, determines the d-c current supplied to the control winding of the saturable reactor.

The electronic circuits in the CA System provide dynamic control with fast transient response and high reliability. Each electrical set has its own individual automation assembly and is thus maintained separately at its own optimum level of operation as a component of the gas cleaning system. The only moving parts in the entire control system are the relays that function on startup and shutdown. The units, being compact and self-contained, can be installed directly on or near the precipitator, saving floor space and high voltage cable. Figure 7 shows a control unit.

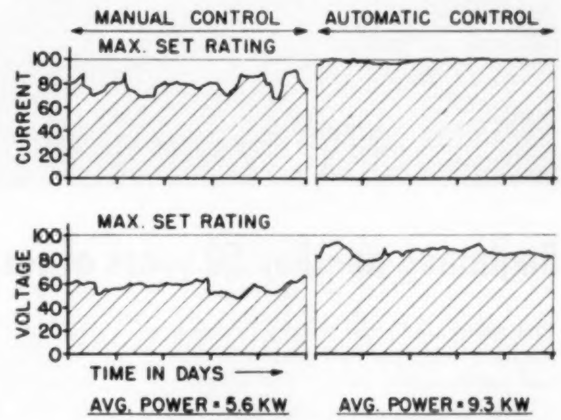


Fig. 6—Performance comparison of automation versus manual control indicates advantages of automation

Westinghouse and Carolinas-Virginia Utility Group to Start Atomic Plant Study

Westinghouse Electric Corporation and the Carolinas-Virginia Nuclear Power Associates, Inc., a group of four southern utilities, plan to develop an atomic power plant for the generation of electricity.

The project will begin with an intensive cooperative study and evaluation of various types of reactors to determine the type best suited to the overall requirements of the Carolinas-Virgina group.

Both Westinghouse and the southern utility group will assign engineers to undertake the study, which will take at least three months, and probably longer, to complete.

The four utilities that comprise Carolinas-Virginia Nuclear Power Associates, Inc., are Duke Power Company, South Carolina Electric & Gas Company, Virginia Electric & Power Company, and Carolina Power & Light Company.

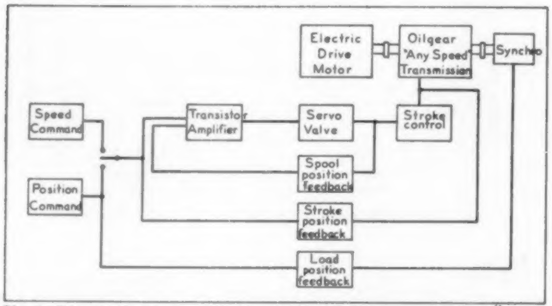


Fig. 1. Block diagram of electro-hydraulic Servocontrolled "any-speed" drive. For draft, pump, stoker, etc. firing control.

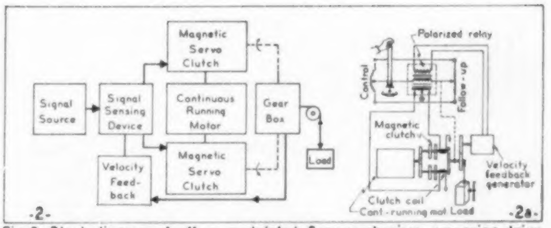


Fig. 2. Block diagram of off-on modulated Servomechanism-reversing drive. Fig. 2a Basic circuit diagram.

Servomechanisms In Combustion Control

By JOHN S. TYNDALL
Elec. Eng.

To meet the demands of today's processes, boiler controls have become more complex. But by carefully planning your own requirements, the author believes, you can develop a control and power system that will do the job economically and efficiently—and with less manpower.

As present-day boilers grow larger and more complex, their control systems must follow closely in the same path. Many designers of this equipment are often awed by the maze of components required to control the modern steam generator efficiently. Yet, if we view these various systems in terms of their several and individual functions, the operations fall neatly into place.

Objectives in applying instrumentation and automatic control to the power plant are: (1) to improve fuel economy (2) to keep overall costs at a minimum (3) to insure safe and reliable operations and, (4) to utilize operating personnel efficiently.

Field for Servomechanism

In the field of servomechanisms as they are being applied more abundantly to the steam plant, the following are of prime interest to engineers.

AUTOMATIC CONTROLS

Combustion, Feedwater, Feed Pumps.

RECORDERS

Steam Flow, Steam Flow-Air Flow, Steam and Water Temperature, Flue Gas and Air Temperature, Drum Level, Feedwater Flow, Steam and Water Pressure, Oxygen Analysis, Smoke Density, Conductivity and pH.

INDICATORS

Steam and Water Pressures, Fuel Pressures, Air Pressures and Drafts.

OPERATING FUNCTIONS

To maintain: Steam Pressure, Combustion Eff.-Furnace Pressure, Drum Level, Feed Supply, Feedwater Pressure.

MISCELLANEOUS SUPPLEMENTARY DATA

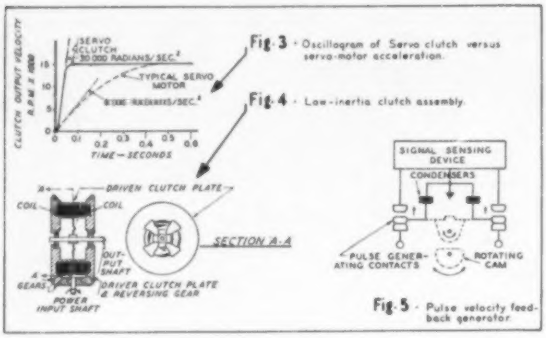
Oil Temperatures, Speed Indicators or Ammeters for Fans, Pumps, Feeders.

Application Problems

In checking over this list of automatic controls that should be applied to combustion control in the form of servo circuits and systems, we find that there are special problems that require special treatment. But those listed above can be economically justified, in the author's opinion, for practically every application above 50,000 lb of steam per hr.

For all practical purposes, the selection of power-drives for the major equipments such as pumps, fans, and stokers will be considered first. A precision speed control from zero to maximum rpm and positive follow-up position control from a remote command unit is available to the industry for modest cost.

Two speed dials (see Fig. 1) and a selector switch on the Command unit provides for two speed selection functions: (1) Dials may be set for two different speeds in one direction and selected by a flip of the toggle switch. (2) Dials may be arranged for "any speed" in one direction and another speed in the opposite direction. Reversal is available instantaneously from the control unit. Further the dials may be manually adjusted, resulting in stepless speed variations in either direction.



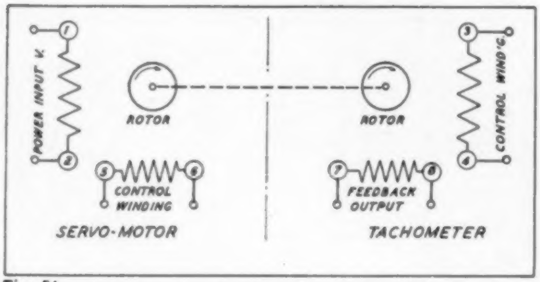


Fig. 5b —Connection diagram of Low Inertia Servo-motor with integrally-mounted A. C. Tachometer Generator. A. C. Servos are primarily designed for "2ø" operation. One phase is excited with an input potential, fixed—the other by a voltage varying in magnitude and direction of the motor output. Of two windings in the tachometer stato, one is excited with rated voltage, the other generates an output potential proportional to output speed. It is a sensitive feedback unit.

In position control operation instantaneous position control is available by merely flipping another toggle switch in the Command unit. Precise stopping positions can be selected at will with the dial from an infinite range of 360 degrees. An electric signal from the Command unit is transmitted to the amplifier, which is provided with "gain adjustments" to allow independent control of two separate input signals. The signal to the amplifier is transmitted to the hydraulic servo valve which accurately controls the flow of fluid from the transmission control cylinder. The control piston positions the slide block in the transmission to provide the desired volume and direction of fluid flow to the output drive unit.

The transmission is equipped with a linear variable differential transformer which produces an electrical signal proportional to slide block movement. If slide block voltage is not identical to "command voltage," the servo valve spool is actuated. The movement of the servo valve spool permits fluid to flow to or from the control cylinder to position the slide block. Any error between the original signal from the command unit to the amplifier unit, and from the transducer unit, will result in repositioning of the slide block. Output speed will remain constant; accuracies from 0.1 to 1.5 per cent can be expected.

The output shaft obeys the initial signal from the command unit (usually located on the combustion-control board) with a high degree of accuracy. The output shaft is directly connected to the Synchro. A feedback signal (similar to the "velocity feedback signal generator of Fig. 2a), is fed to the command unit and compared to the original signal. Any error will signal the servo valve and the output-shaft speed or position will be corrected accordingly. This circuit is in operation only when the drive circuit is energized. This servo power drive has been successfully introduced in industry for application on numerous machine drives and operations and is now being developed to serve those peculiar drives in the power plant combustion processes.

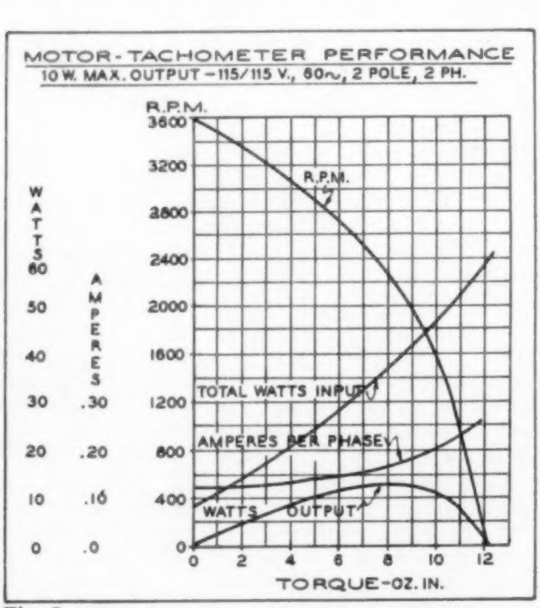


Fig. 5c — Typical performance chart of servo unit illustrated in Figs. 5a and 5b. Motor-Tachometer combinations are also furnished with high impedance control windings for operation directly from the plates of vacuum tubes. A-C or D-C operation.

Modulated Reversing Clutch Servo Systems

As cost and reliability are critical factors in combustion control development, it is suggested here that simpler, more sturdy non-linear electromagnetic servo controls should be considered. They can approximate closely the performance of a proportional type of control by the use of velocity feedback and power gains of up to 50 times in the servo magnetic clutch with direct operation from the primary (or signal-sensing) control element.

The application of servomechanisms to combustion control is largely the result of the last 10 years of supervisory development. Ten years ago many steam plants had no servo systems. In this period, each year has seen an approximate doubling of the planned use of such controls. Today a major portion of the total supervisory cost is invested in servomechanisms of one type or another. The industry is progressing toward an immediate planned future where the engineer will exercise only a monitoring function over the servomechanisms which will take over combustion control.

The early electric and hydraulic servomechanism was required to be supplemented by manually operated mechanical controls. It is doubtful if today's servomechanisms, with their increased complication, have any greater net reliability. Yet, in many cases, the requirement for parallel auxiliary mechanical control has been eliminated. While this elimination sometimes has been unavoidable due to the complicated functions required of present controls, it usually cannot be justified

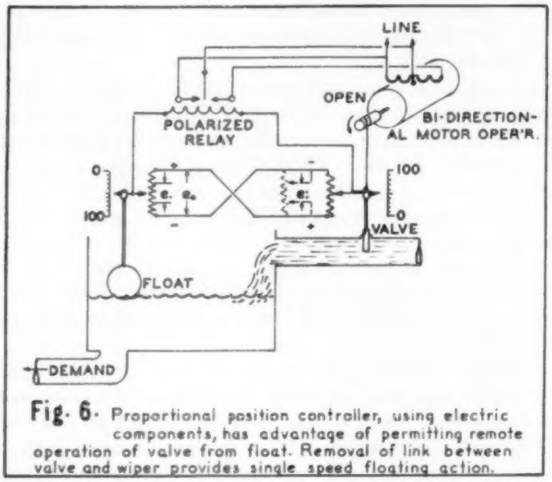


Fig. 6. Proportional position controller, using electric components, has advantage of permitting remote operation of valve from float. Removal of link between valve and wiper provides single speed floating action.

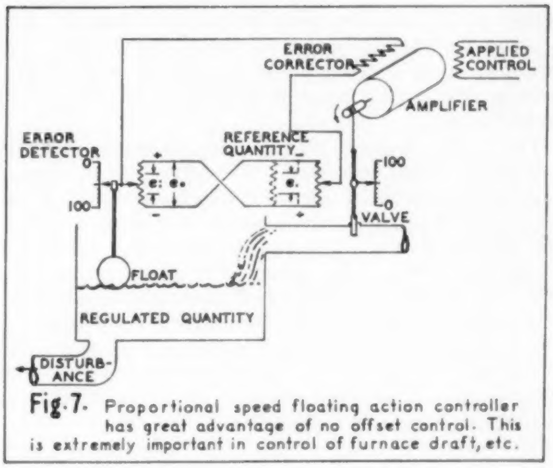


Fig. 7. Proportional speed floating action controller has great advantage of no offset control. This is extremely important in control of furnace draft, etc.

on the basis of improved reliability of present servo controls. Unfortunately, as the complexity of a control problem increases a point will be reached where a mechanical control is no longer the most reliable. A further increase in requirements can make direct mechanical controls impractical, as, for example, the control of modern recorder and indicating systems.

The rapid expansion of servomechanism application has caused plant operation and financial problems of a critical nature. The size and effectiveness of plants is being limited by the rapid rise in cost of combustion equipment. No small part of this rise in cost is due to the high cost of complicated electronic servo devices. Also, the general failure of electric servo reliability to progress at a rate commensurate with the increased responsibilities now being given supervisory servo control is one of the principal causes of an alarming number of apparatus casualties, man-hours required for maintenance and operation, and equipment nonoperative hours in a typical plant. But things are improving rapidly.

Attention should be drawn to an improved type of nonlinear or "on-off" servomechanism. Development of the on-off servomechanism has been bypassed to a large extent because of the complexity of nonlinear mathematical analysis. Electric contact and mechanical problems have also discouraged this control approach in the past.

Experience with on-off servos, however, has demonstrated that relay and magnetic clutch problems can be solved if they are seriously approached. The resulting device has the possibilities of being less complicated, more rugged and reliable, and of having better acceleration characteristics than proportioned controls of similar application in the plant.

The off-on servo is distinguished from conventional servos of this type in that it incorporates velocity feedback and high-speed servo reversing clutches. Servo power is obtained from a driving motor operated continuously in one direction. The servo function is performed by direction-of-rotation-reversing magnetic clutches.

The combined use of velocity feedback and high-speed reversing clutches in an on-off servo elevates its performance to that compared with proportional servos while still retaining the basic simplicity of the on-off control principle. For example, single-stage control accuracies of 0.1 per cent of total travel can be obtained. This accuracy results because the low time constants in the servo system as a whole provide single-step travels as small as 0.05 per cent of total travel.

A further advantage of an off-on modulated servo is that acceleration performance may be obtained from an all-electric servo which presently can be obtained only from combined electrohydraulic or electropneumatic systems. As an example, electric-actuator accelerations of 50,000 to 100,000 radians per second per second can be obtained. By comparison, conventional hydraulic actuators have accelerations of about 20,000 radians per second per second.

Off-On Modulated Reversing Clutch Servo

In the functional block diagram, Fig. 2, the "signal source" for the subject servo may be any of the common a-c or d-c types. Signal generating and follow-up pairs of resistance potentiometers or "selsyn" units may be used. Resistance thermometer bridges or variable reluctance bridges yielding displacement, acceleration, or strain signals are suitable signal sources.

The "signal-sensing device" in its simplest form may be a polarized relay or for a-c signal systems, a ring demodulator and magnetic amplifier. Due to the power

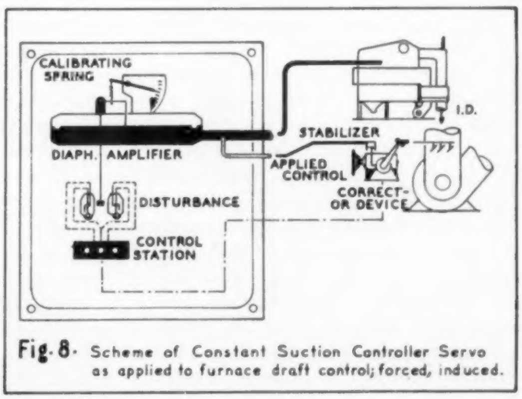


Fig. 8. Scheme of Constant Suction Controller Servo as applied to furnace draft control; forced, induced.

amplifying properties of a magnetic servo clutch, the output of the signal-sensing device often may be used to control directly the servo clutch power unit. For example, in its simplest form a polarized relay signal-sensing device may control directly a 30 kw output servo clutch.

The block diagram, Fig. 2, also shows a "velocity feed-back" signal generator. This generator provides a velocity proportional negative feed-back signal to the sensing device and is driven by the follow-up action of the servo actuator. The velocity feed-back signal can be adjusted to a value which will cause a controlled series of off-on modulations of the servo-clutch units in a manner to produce any appropriate deceleration of the actuator as it approaches the desired control point. These off-on pulses of the servo clutches may be made small enough so that for all practical purposes the servo output is a uniform motion.

The remaining units in Fig. 2 are the two magnetic reversing clutches, the continuously running motor, and the actuator gearing. These units, together with the feedback generator and the follow-up signal source, are assembled into the servo actuator.

A power gain of over a million may be reliably obtained from even a simple form of this system such as the polarized relay, clutched servo shown in Fig. 2a. For example, a typical modern polarized relay can be made to operate reliably on a 300-microwatt input signal. Such a relay equipped with an adequate contact protection network is capable of controlling as much as 10 watts of electric power. This amount of power can in turn control a magnetic servo clutch of several thousand watts. The foregoing values are conservative and are not based on speculative development of components such as magnetic power clutches which may or may not prove to be superior to the simple disk friction clutch using time-proved materials and design. The point is, that these results can be expected from using the non-speculative design of components to be described in more detail in the following sections.

Magnetic Servo-Clutch Power Unit

Several types of servo clutches have been employed in the past in industry. Most popular of these in the initial stage of servo-clutch development was the proportional clutch. In one proportional clutch design, two clutches were geared to drive the output shaft in opposite directions. These clutches were maintained in slight engagement in the normal or zero signal position. An error signal would cause the increased engagement of one oppositely driving clutch and decrease the engagement of the other. This action caused a positive rotating force on the output shaft which corrected the position of the actuator and thus eliminated the error signal. The object of this type of servo clutch was a torque output proportional to the control signal.

The proportional type of servo clutch has the advantage that it provides a theoretically infinite positioning characteristic necessary for system stability in high-accuracy servos. Also and not the least of its attractiveness, is that it is considerably easier to treat in a mathematical analysis than the nonlinear on-off clutch. The proportional clutch has the disadvantage, however, in that the attempt to maintain proportional control between mechanical drive members involves slippage, severe clutch heat dissipation problems, and a somewhat low efficiency.

A more direct approach to the problem of servo-clutch design is to admit that the most efficient clutch operation can be obtained with the simple and positive engagement of a dry-disk clutch. Then, if provisions in the servo system are made to off-on modulate this nonlinear control device a close resemblance to the desirable proportional control can be obtained. On the whole, pulsing the clutch in and out for a number of pulses may result in less internal problems and better mechanical efficiency than a clutch which is allowed to slip continuously to accomplish the same purpose.

Another advantage of the on-off servo clutch is that its control accuracy is not a function of the actuator gearing load or the variable load that might be coupled to the actuator output. With a positive action servo clutch, the servo-control accuracy is determined only by the electrical dead space in the sensing element.

The important concept is that a simple and straightforward clutch can be made very effective for servo control. The simplicity afforded by magnetic dry-disk clutches allows a designer to put most of his effort into the details of design which make a clutch reliable instead of having to put the majority of his effort into making some new type of clutch function.

The primary design problem in a dry-disk servo clutch is controlling the wear that results when the servo load is coupled into the continuously rotating servo motor. The life that may be obtained from a dry-disk clutch is determined by this wear. Clutch failures from excessive wear can result from mechanical failure of the clutch plates or an excessive increase in clutch gap.

In the past, popular clutch materials have been soft metal, cork, or composition material similar to that used in automobile clutches. The real success of the power type servo clutch, however, has resulted because more durable clutch face materials have been applied. For example, a rugged servo clutch with a life of tens of millions of operations has been obtained by using a case-hardened steel surface operated against a cold-rolled steel surface. Another successful clutch facing has been a polished chrome-plated surface operating against a cold-rolled steel surface. Clutch combinations of stainless steel against case-hardened steel also have proved successful, as have magnetic-coupling clutches.

One of the most important considerations in a servo-mechanism design is the speed of response. It is necessary that the power-controlling devices start and stop the mechanism rapidly. With such high-speed operation the servo dynamic error is reduced and stability improved. There is also less chance that the actuator will overshoot on speed and cause system malfunction.

High-speed response is difficult to obtain with a typical power-relay and servo-motor type of control because of the inertia of the motor armature. In typical mechanisms it has been demonstrated that in excess of 90 per cent of the actuator inertia is contained in the motor armature. Furthermore, time lags in the power relays required to control the large currents of the servo motor slow down the operation of the servo. A clutch and brake built into the servo motor may assist by removing the motor armature inertia from the stopping cycle problem, but it will not improve the starting char-

acteristic. In any event, the servo-motor time requirements must be added to those of the normally required power relay.

When a reversing servo clutch is used with a continuously running motor, however, the inertia of the motor armature can be moved from the debit to the credit side of the design ledger. The servo clutch utilizes the stored energy in the continuously running motor armature for high starting acceleration. Actuation time of the servo clutch itself is no greater than a typical power relay. For example, an a-c servo clutch requiring 1000 watts of power for actuation and capable of controlling a 10,000-watt stoker motor can be designed to have an operation and a release time of 5 milliseconds each. This would be a better than average performance for commercial control relays designed to handle the same power.

Comparative acceleration characteristics of a servo clutch and servo motor are shown in Fig. 3. In this example the servo clutch accelerates at 30,000 radians per second per second or five times faster than the servo motor.

One of the conflicting design problems in an on-off servomechanism is that of providing adequate power for system acceleration while retaining the small pulse travel needed for stability of the system as a whole. In an on-off servomechanism it is necessary for stability that the minimum pulse travel or step sensitivity within the control dead space be established by the sensing element. It would seem that this requirement in an on-off servo would be defeated by employing a high-acceleration magnetic servo clutch. Such is not the case, however, if the clutch is designed to provide a few milliseconds of starting slip. With this provision it is possible to obtain a step sensitivity equivalent to or better than a servo-motor design, using in both cases the identical motor, actuator, and load characteristics. A starting slip characteristic is shown in the servo-clutch oscillogram of Fig. 3.

Where high accelerations of the servo-clutch system are desired, excellent torque to inertia ratios may be secured with a simple disk clutch as shown in Fig. 4. Here a disk made from magnetic material is cut away at the center to provide both the necessary spring action and the flexibility to allow the rim of the disk to engage the driving magnets. Clutch disk travel would be of the order of 0.05 to 0.1 in. The flexing support members are shown beaded in Fig. 4 to allow for angular alignment of the disk clutch face with the magnetic driving units. For a servo-clutch power type typical of the size being described in the 2000 to 30,000 watt output range, the clutch disk could be made from materials $^1/_2$- to 8-in. thick. Such simple designs require careful mechanical refinement but little of the speculative research characteristic of many current experimental proposals and can be expected to have substantial production cost advantages.

The use of magnetic clutches is attractive in servo control because these devices are efficient transducers of power from the electrical to the mechanical form. Servo clutches both transform and amplify power in the same operation. The efficiency of power conversion may be demonstrated by comparing a typical 300-watt output servo motor to a 300-watt output servo clutch. With the servo clutch, 300 watts of mechanical output power may be controlled with 10 watts of electric power (input). A 300-watt output from a servo motor, however, would require approximately 500 watts of controlled input power. In this comparison, therefore, the servo clutch alone shows a power amplification of 30 to 1 and an advantage over the motor of 50 to 1 in the amount of electric power required to control a 300-watt mechanical output.

Velocity Feedback

The application of velocity feedback to off-on clutched controls eliminates performance to a level competitive with proportional controls. Velocity feedback is the brakeman on the servo gear train. Its function is to stop or brake the actuator at the position or speed prescribed by the signal-sensing device without overshoot or oscillation. In order to accomplish this job, the velocity feedback first must sense the actuator order required at any velocity and then signal when to start the new operation. In on-off controls, velocity feedback provides a damping characteristic by time modulation of the servo clutch. At a point predetermined by the initial velocity signal, the servo clutch is off-on pulsed to obtain the desired deceleration to the selected stopping point, or vice-versa.

A simple type of velocity feedback is proposed as shown in Fig. 5. With this method a velocity signal is generated by integrating a series of capacitor pulses obtained when electric contacts are operated. These contacts are opened and closed at a rate proportional to servo velocity. Polarity of the feedback signal is obtained by actuating either one of two sets of contacts according to the direction of the driving cam rotation. The feedback generator described is only one of many types that can be employed in servo controls. The most common is the tachometer generator. This type of feedback source generates a signal proportional to velocity and is the type most often employed.

One point that should be emphasized about applying feedback in off-on servomechanisms is that such feedback should not be used to compensate for slow electromechanical operation. Every effort should be made to purge the basic servomechanism of unnecessary inertias, complaisance, and time lags. Then rate feedback should be added as an addition to the basic performance. The approach of making the basic system sound before refining it with velocity feedback has three advantages:

(1) The feedback circuit, except for insulation, is reduced from a series to a parallel liability. That is, failure of the velocity feedback unit does not cause servo failure.

(2) When velocity feedback is finally added, the system performance improves. For example, the step sensitivity of the servo may be increased many times.

(3) Less feedback voltage is required.

The amount of velocity feedback required can be determined from an analysis of the servo stopping characteristic. The velocity feedback signal required is merely the error signal cancelled during the speed control interval. If, for example, the servo at a particular velocity cancels the error signal at a rate of 0.1 volt per millisecond and the stopping operation consumes an effective time of 50 milliseconds, a feedback signal of 5 volts is required for critical damping.

Signal-Sensing Device

To obtain a type of servomechanism which achieves performance without the sacrifice of simplicity, a simple clutch power unit and feedback generator is suggested. It is appropriate, therefore, to complete this discussion with the simplest possible signal-sensing device—the polarized relay.

A simple contact arm and actuating coil comprising a relay is perhaps the most efficient, lightest, and most stable device for getting power amplifications of the order of 50,000 to 1,000,000 watts. With these advantages it seems worth while to give the polarized relay a chance by providing at least the same degree of engineering attention to its design and application that would be given to competing electronic and magnetic amplifying devices.

Substantial progress in the design and application of polarized relays to combustion control has been made recently. Much of the current objection to power plant use of polarized relays may border on prejudice. Such prejudice has resulted from former attempts to use polarized relay devices not adapted to this environment or to serious misapplication. Under the category of misapplication may be included the use of any sensitive contact-making device without a thorough investigation of the contact problems and the design of appropriate contact protection networks.

It is believed that up-to-date relay units with adequate contact protection networks can be applied to drive-controls in a manner to insure adequate reliability.

Conclusions

(1) The demand for improved reliability in combustion servomechanism control is increasing at a faster rate than the actual growth of reliability. This reliability factor together with the cost of industrial servomechanisms is a limiting factor in the supervision and effectiveness of thermal production.

(2) Simplification is the first step in improving servo reliability and reducing cost. Electric on-off servocontrols are simple and have been based on nonspeculative design which incorporates rugged electromechanical elements.

(3) The combined use of feedback and servo clutches in an on-off servo elevates its performance to that obtained with continuous control while offering the possibilities of lower cost and weight, greater simplicity and reliability. Single-stage control to 0.1 per cent of full speed is practical.

(4) All-electric off-on modulated control can match response characteristics presently obtainable only with hydraulic or pneumatic controls. Accelerations of 1,000 to 100,000 radians per second per second are obtainable.

(5) The off-on modulated type of servo unit is adaptable to large plant servo control applications presently using hydraulic or electrohydraulic servos. The subject unit would offer the advantages of all-electric control while avoiding the critical motor starting problem, associated line disturbance, and brush problems of a servo-motor control, as well as maintenance of perfected air and oil networks.

Most common forms of integral action are usually expressed in terms of floating action or as reset. Reset, however, is applied here only to a particular form of floating action when used with proportional position action.

Integral Action In Automatic Control

Floating action may be subdivided into the common types: (1) single speed floating and (2), proportional speed floating. To conveniently illustrate single speed floating action, the mechanical level controller is converted into an electrical controller—thence to servo control. Initially, its proportional action is retained.

This is shown in Fig. 6. Assume that the transmitting slide-wire position is exactly balanced by the rebalancing slide-wire position. When this condition of the bridge holds, there is electrical balance. If water level in the drum, deaerator tank, heater reservoir, or water softener system drops the transmitting, or error-detector circuit, moves downward.

This puts the transmitter at a potential more negative than that of the rebalancing, or reference quantity potentiometer. Current flows from negative to positive through the coil of the polarized relay. When current flows in this direction, the armature is moved to the right to make contact with the counterclockwise terminal of the servo motor or power unit.

The motor shaft revolves in a counterclockwise direction and the wiper of the rebalancing reference-quantity potentiometer is moved upward to a more negative position. At the time it reaches the equivalent negative position to which the error-detecting slide wire has moved, no current flows in the polarized relay and its armature (or contactor) returns to the neutral position. Thus, rebalancing has occurred and, in doing so, the servo motor has also lifted the gate valve or final control element. The converse of this operation is also true.

Proportional band control is added to this servomechanism by controlling voltage to either or both of the slidewires. The broken lines in Fig. 6 shows a proportional band adjustment potentiometer, or controlled signal, to adjust voltage across the reference quantity slidewire.

Suppose that the proportional band adjustment potentiometer wipers are moved closer together as shown so that the potential, e, is 50 per cent of the potential, e_0, applied to the transmitting, or error-detecting slidewire. When this is done, it can be seen that full range movement of the rebalancing slidewire wiper must be obtained for the movement of the transmitting slidewire wiper to equal the voltage range shown by e. Since the full operating range of the final control element is 100 per cent and the range of values of the controlled variable is only 50 per cent, the proportional band can be expressed as:

$$100\,\frac{\theta}{V} = 100\,\frac{0.5e_0}{e_0} = 50\%$$

Integral Action

(Single Speed Floating Action). To illustrate this action, the link between the final control element and the wiper of the reference quantity slidewire is removed, as is shown in Fig. 7. The wiper is then moved manually to a position representing the desired set point—its function now becoming regulated quantity as well as reference quantity—termed the set-point adjustment.

Assume that equilibrium conditions are obtained, i.e, the position of the float or transmitting slidewire wiper is electrically equal to the set point. When demand increases, tank level decreases, thus dropping the float and its slidewire to a more negative position. This unbalances the circuit, and the gate valve is opened by the previously described action of the polarized switching of power to the servo power unit. It continues to open more and more until the water level in the tank or drum increases to a point where the float places the potentiometer wiper in that electrical position equal to that of the set-point reference. Then, the electrical circuit becomes balanced and the motor operator deenergized.

However, the gate valve may have been raised or opened to a position greater than that required to maintain demand level at the set point. If this is true, the level will continue to rise and the circuit will again become unbalanced but in the opposite direction. This will allow the gate valve to drop, decreasing the flow of inlet water. however, this *can* become a cyclic recurrence known a "hunting" or oscillation. Tendency of the single speed floating action controller toward hunting or continuous oscillation is one of its great disadvantages. One of its primary advantages, however, is that trait of never suffering from any offset plus the fact that it is adapted to control of non-linear final control elements found so prevalent in the modern power plant.

Proportional Speed Floating Action

It can be seen in the following example that, when a small increase in demand flow occurs, the rate of change of tank level will be small. Motor speed is required proportional to the deviation. This type of action can be obtained and is known as proportional speed floating servo control. See Fig. 7.

Here, the polarized relay is replaced directly by a portion of the armature winding of a d-c motor having a separately exciting field. The former field (or relay winding) is referred to as the error-correcting coil, whereas the latter is referred to as the applied control. Rotational speed of this servo motor is directly proportional to the voltage across the armature circuit, or torque amplifier. Direction of rotation is determined by the direction of current flow through the armature circuit. With this arrangement, if the change in demand flow is small, the level change is small, and vice versa.

Therefore, if a large sudden drop in level occurs, the motor speed will at first be great and raise the value at a fast rate. As the inlet flow rapidly raises the float potentiometer, the voltage difference is reduced, reducing current flow and producing a gradual reduction in motor rpm proportional to the increase in level until the "set-point" is reached. The proportional band potentiometer in this example controls the voltage appearing across the controlled variable (reference quantity), which affects, in turn, the amount of voltage appearing across the servo motor for a given deviation from set point. This determines the motor speed for that deviation. (It might interest power engineers to know that this servo control for proportionment has been applied to the arc-rods of projection machines for many years.)

Proportional speed floating controllers are the "work horses" in most phases of boiler control. Typical of these applications are boiler feedwater control, superheat and reheat controls, and fuel-air ratio demands.

Proportional speed floating action in the servo field is obtained in the majority of diaphragm unit controllers by adding a piston type pneumatic pump, driven by the motor operator or power unit. This pump is referred to as the feedback or stabilizer piston. Its output is connected into the diaphragm amplifier impulse line to partially oppose any change.

Electric Control

A typical controller of this type is illustrated in Fig. 8, which shows a constant suction type controller used to operate an induced draft fan damper. The fan drive itself is driven by the servo power unit previously described. Furnace draft applied to the diaphragm is balanced by the calibrating spring, or governor. Unbalance produced by an increase or decrease of furnace draft from the set point (reference quantity) moves the magnet arm to close either the increase- or the decrease-switch, respectively creating disturbance in the power unit—thus opening or closing, as demanded by the error correcting stabilizer.

Initial motion of the power unit is at a constant speed (with gear-train reduction). This motion, while changing the damper position in a direction to correct the draft deviation, also operates the feedback piston, which develops air pressure in the diaphragm in a direction opposing the change in furnace draft. This causes the associated mercury switch to open and the servo power unit to stop and remain positioned.

Within a short period, pressure developed by the piston is absorbed in the furnace draft line. If a deviation from the reference quantity still exists, the mercury switch again closes and the above sequence of events is repeated. Thus, power unit motion is a series of on-off, forward-backward steps which, when integrated with respect to time, exhibit speeds proportional to the deviation. This is illustrated graphically in Fig. 9.

Electronic Servo Control

A servo type electronic controller is applied whenever greater threshold and resolution sensitivity are desired. Its dead band and hysteresis characteristics are correspondingly less. Action of the servo electronic controller can be either proportional position or proportional speed floating. Fig. 10 shows its application as a fuel-air ratio controller, for instance. An electronic amplifier raises the deviation signal level, detects it, and controls a pair of relays for controlling the increase and/or decrease windings of the servomechanism operating the fuel-air ratio components.

While the rotational speed of the power unit is at a fixed rpm when energized, action of the amplifier is to energize the servo motor intermittently. The on-time to off-time ratio of applied motor energy is proportional within limits to the deviation and can be adjusted by means of the dwell, or applied, control at the ratio adjustment point. This, as in the case of the constant suction controller, provides a series of on-off steps of the servo-motor shaft rotation which when integrated with respect to time effectively provides proportional speed floating action via servo application.

Servo System of Frequency Control

(**Power and Instrumentation**). For the control of alternator (or bus) frequency and for the provision of power

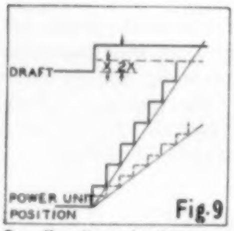


Fig. 9

On-off motion of motor operator (power unit) plotted versus a pair of steady state values of deviation. Integrated motion with time (speed) is proportional to deviation.

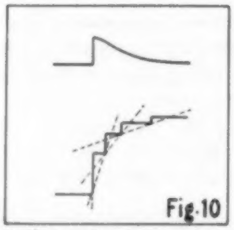


Fig. 10

Typical proportional speed floating action showing deviation, corresponding motor operating motion, and deviation reduction occurring during a load (steam demand) change.

to certain types of combustion-control instruments, a source of alternating current is required in which the frequency error must be ±0.1 per cent or less over a range of temperatures, loads, and supply voltages. This need has recently been met by the development of a small motor-driven alternator which receives its power from one of the house exciters or d-c generators. (Rectified power is also acceptable.) Frequency regulation is accomplished by shunt-field current control in the motor, and the field current is controlled by some form of servomechanism and frequency-sensing device.

In order to overcome the limitations of existing frequency-regulating devices, the magnetic amplifier type regulator described herein was developed. This new regulator has no moving parts (the m-g set is remote), is extremely accurate in performance, and is not affected by shock, vibration, atmospheric conditions or voltage fluctuations at the motor-alternator set. Its schematic diagram is shown in Fig. 12.

The frequency control system consists of these components:

A. Dynamotor for d-c to a-c conversion.

B. A small permanent magnet a-c pilot generator attached to the dynamotor shaft.

C. and D. A pair of series-resonant circuits with rectifiers.

E. A magnetic amplifier, consisting of two toroidal reactors and two self-saturation rectifiers.

F. A control field rectifier.

In operation, two series-resonant circuits C and D are excited by the output of pilot generator B and supplies rectified control currents to the magnetic amplifier E. The magnetic amplifier controls the current flow to the control field rectifier F, which in turn, supplies rectifier current to the control field of the dynamotor. In addition to the principal circuit components, an electric damping circuit is utilized, consisting of capacitor c_1 and two auxiliary windings on the magnetic amplifier reactor cores. The damping circuit is connected in parallel with the control field winding and produces a magnetomotive force in the magnetic amplifier which is a function of the rate of change of voltage across the rectifier. This additional magnetomotive force acts in a direction to stabilize the frequency of the system.

Temperature stability between 40 and 130 deg F is obtained by the use of temperature-stabilized Permalloy dust-reactor cores in the two frequency-sensing circuits.

The magnetic amplifier E in Fig. 12 consists of two ribbon-core toroidal reactors, each of which has four separate windings. The directions of the magnetic fluxes in the reactor cores are shown by the arrows in the illustration. When the dynamotor frequency is exactly 60 cycles, the ampere-turns in the pairs of control windings on each reactor are "equal and opposite." When a disturbance in load or supply voltage occurs, the resonant-circuit currents become unbalanced and the reactance of the magnetic amplifier increases or decreases as a function of the net control currents from the sensing circuits The saturable reactors, in turn, regulate the current to the control field coils of the servo-dynamotor in such a manner as to restore the frequency to that value previously selected by the reference quantity unit control—usually 60 cycles. (Units are manufactured for 25-, 30-, 40-, 50-, $66\frac{2}{3}$-, and 120-cycles.)

Transient response tests on the system indicate that the frequency will return to normal in two-thirds of a second after a critical load is applied or removed from a turbogenerator or instrument bank consuming this current. When the frequency control system is serving a standard voltage-frequency regulator, the response correction will vary with the device used—varying from one to as much as three seconds. Or, following a serious surge in the supply voltage to the servo-motor-generator unit, as much as ±5.0 per cent. Most of this time delay can be attributed to the inertia of the dynamotor as well as the inertia inherent in standard voltage frequency regulators to which this servo device has been connected merely as an actuator plot.

To summarize, this magnetic-amplifier servo frequency control has the following advantages over older devices designed for the same purpose:

1. At normal temperatures the system demands frequency control (or regulation) of the order of one part

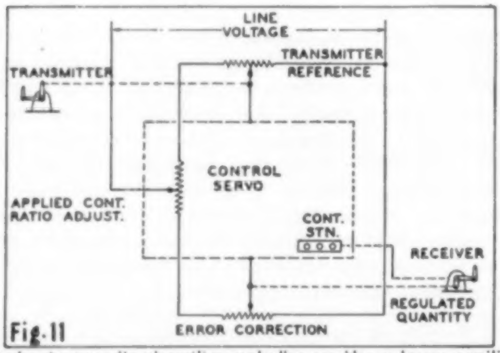


Fig. 11

Electronic proportional position controller provides extreme sensitivity through use of thyratron relay tubes. Ratio between sending and receiving potentiometer position is adjustable.

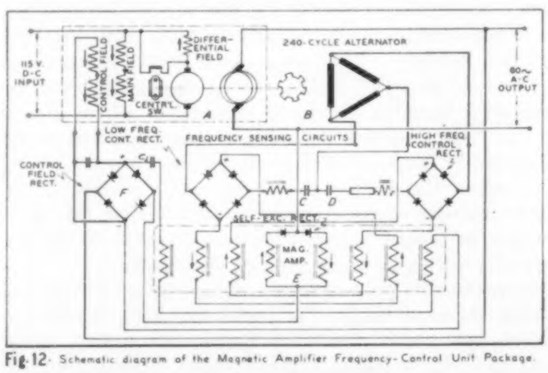


Fig. 12. Schematic diagram of the Magnetic Amplifier Frequency-Control Unit Package.

in 5000 or better without the aid of tachometers, tuning forks, crystals, or vibrating reed consoles. Turbine governors, of course, will be used in conjunction with the system where no outside sources of power are tied into the plant system via synchronization.

2. The system is stable in operation under fluctuating loads, voltage, and operating temperature conditions.

3. Other than the m-g servo, there are no moving parts in the system.

4. The regulator is simple in design and inherently free from maintenance troubles, and is not affected by shock, vibration, or installation misalignment usually encountered in use.

This frequency control is an example of the successful application of the servo-type magnetic amplifier to a practical combustion problem—albeit at the turbine and/or control board area—and is smaller, lighter, and more effective than other controls designed for the same purpose.

THEORY

The following treatise is a theoretical analysis applicable to servomechanisms in the combustion field as well in mill, factory and plant.

Stabilization Templates For Servomechanisms

In the process of design, the power and application engineer must consider the change in the system transfer functions due to corrective networks added in cascade. Instead of a trial and error adjustment of the network parameters, templates for different corrective networks and prototype systems are drawn, which show the change in gain and phase.

Referring to Fig. 13, the templates are used with transfer function plots on coordinates of decible gain versus angle. This applies to power-type servos as well as the more sensitive instrument servos. These coordinates are used for the display of the open-loop transfer functions of a servomechanism, so that the addition of stabilization networks can be shown as loci. Any cascaded network will have for each frequency a specified phase shift (angle) and a specified change in gain. These can be represented by a particular length of line on this coordinate paper.

The template of the gain-phase shift of the stabilizing network can be used with other types of transfer functions by moving laterally or vertically. The intersection of the template and the transfer function gives the parameters of the system and the upper end of the template gives a point through which the new stabilized system will go.

If the shape of the actual transfer function at high frequencies is similar to that of the prototype, then the shape of the stabilized system at the critical frequency will also be similar to that of the prototype.

An open-loop transfer function of an integral with one time constant is shown in Fig. 13. Dimensionlessly it is $G_s = \theta_0/\theta_e = K/ju_1\,(1 + ju_1)$. All of these functions are identical except that they occupy different vertical positions depending upon the value of K.

If the original system were cascaded with a lead network, whose low-frequency time constant equals that of the system's, then these time constants would cancel and the resultant system would also appear to be an integral plus one time constant. If additional gain were added, and then the transfer function expressed in dimensionless form, it would have an optimum adjustment at $M = 1.3$ or $K = 1.36$. Fig. 13 shows this optimum or compensated prototype system.

Consider the requirement of stabilizing a system whose required d-c gain is so great that the transfer function represented by the foregoing equation cuts through the $M = 1.3$ contour. Use a lead network with a ratio of time constants of k and an additional gain of k. The transfer function of the composite system is: $G_cG_s = K(1 + j\omega kT_2)/ju_1\,(1 + ju_1)\,(1 + j\omega T_2)$. To cancel the numerator factor, let $\omega kT_2 = u_1$, and $\omega T_2 = u$. This compensated system should be through the point A, gain of one at 135 degrees lag. If G_cG_s is set equal to $(-0.7 - 0.7j)$ at a value of u of unity, K/k is 1.4.

The transfer function of the original uncompensated system, is $G_{so} = 1.4/j(1 + jk)$. This is the equation for the locus of all the points on Fig. 13 which can be moved to point A by a single lead upper crossover frequency. This locus is plotted; it has only one parameter, the ratio of time constants of the lead network. The intersection of any unstabilized curve with this locus yields the values of k and u_1 for the upper crossover frequency of the lead network. The design is therefore complete.

If the original system were stable, but the speed of response not sufficient, the original transfer function

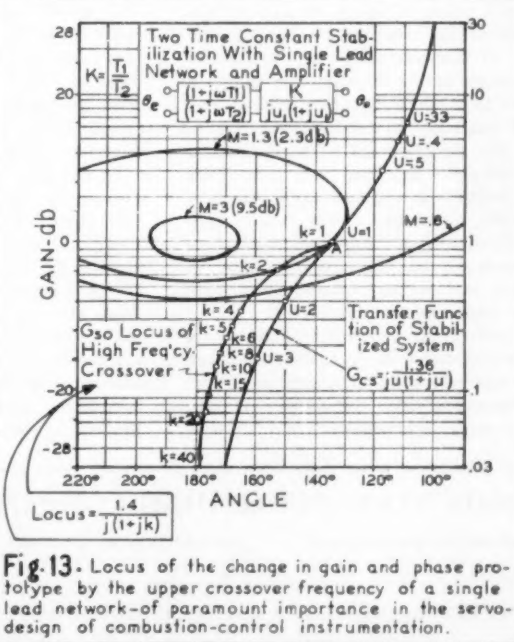


Fig. 13. Locus of the change in gain and phase prototype by the upper crossover frequency of a single lead network—of paramount importance in the servo-design of combustion-control instrumentation.

should be plotted on transparent paper, laid over the template of Fig. 13, and then moved in a vertical direction until the intersection of the stabilizing locus and the original transfer function occurs at the new desired new critical frequency or new resonant frequency. The intersection gives the lead network design and the vertical shift is the additional d-c gain in decibels required.

A lead network was used here for illustrative purposes because of its simplicity. Templates may also be constructed for networks for reducing noise susceptibility, and for complex pole-zero pairs. These templates aid greatly in the rapid and systematic design of feedback and velocity feedback systems.

Assistance was greatfully received from the following companies for information on the application and functions of Servomechanisms:

Leeds & Northrup Co.
Fisher Governor Co.
Diehl Mfg. Co.
The Hays Corp.
Minneapolis-Honeywell Co.
Bailey Meter Co.
Consumers Power Co.
The Detroit Edison Co.

REVIEW OF NEW BOOKS

Any of the books here reviewed may be secured through Combustion Publishing Company, Inc., 200 Madison Ave., N. Y.

Reactions of Carbon with Carbon Dioxide and with Steam

By C. G. von Fedarsdorff

Institute of Gas Technology Research Bulletin No. 19, 76 pages, $7.50

This bulletin contains the results of ten years of study of two of the fundamental reactions in the production of manufactured gas. Studies of reactions in the temperature range of 1700 to 2500 F between a solid fuel and oxidizing gases are presented as (*a*) the development of mathematical procedures which may have general use in estimating physical and chemical factors associated with carbon gasification, and (*b*) application of these procedures to the interpretation of steam and carbon dioxide decomposition rates and gas analyses.

Most of the experimental data were obtained with continuous-flow fixed-bed reactors operating at atmospheric and superatmospheric pressures in the Institute's laboratories in Chicago. Results reported by others are analyzed in a literature study and addendum.

Design of Piping Systems

John Wiley & Sons, 365 pages, $15

A second edition of this authoritative book has been prepared by members of the engineering departments of The M. W. Kellogg Company. A complete investigation of structural design is included with emphasis on the flexibility analysis of critical systems.

In chapters I and II, Strength and Failure of Materials and Design Assumptions, Stress Evaluation; and Design Limits, and again in the third chapter on Local Components, which treats the effect of piping reactions on local and terminal components of a piping system, there is much material to aid the designer to understand the significance of stresses in piping performance. Chapter 4, Simplified Method for Flexibility Analysis, contains several newly developed approaches that facilitate the general assessment of average piping or are helpful in the planning stage of critical piping design.

Offering an unusually complete treatment of the thermal expansion problem, the new edition also gives a method for calculating the effects of uniform loading, such as that due to weight or wind. A chapter entitled Supporting, Restraining, and Bracing the Piping System covers the various problems of supporting critical piping systems, while a chapter on Vibration: Prevention and Control approaches the subject from the standpoint of the piping designer, with the objective of achieving vibration free piping in the design phase of a subject.

Other chapters deal with flexibility analysis by the general analytical methods and by model test, and approaches for reducing expansion effects. An extensive appendix includes the history and derivation of piping flexibility analysis, derivation of acoustic vibration formulas, and various charts and tables.

The engineering profession has received many benefits from the willingness of companies to share technical information, much of which was originally developed at great expense to individual organizations. This book is an outstanding example of such enlightened sharing to the benefit of all.

The theory of the throttling calorimeter is reviewed. Speculations upon the irreversible expansion of wet steam are presented. On the basis of experimental work by other investigators, and a two-phase analysis of the physical factors, it is shown qualitatively that the expansion is completed prior to the phase change.

The Throttling of Wet Steam

By J. H. POTTER*

Stevens Institute of Technology

ANY attempt at an analysis of the throttling of wet steam must be based upon a physical picture of this fluid. There is general acceptance of the definition of wet steam as a mixture of dry saturated vapor and saturated liquid at the same temperature and pressure. However, there is very little information on the form of the liquid in this mixture.

Early workers in the field assumed that the dry steam exhibited gaseous behavior and that the liquid phase was present in the form of large drops. Superficially this was borne out experimentally, as the separating calorimeter apparently demonstrated. Carpenter (1)[1] claimed that, on the basis of nearly 100 observations on a separating calorimeter, the exit steam quality averaged 99.998 per cent. This statement must be weighed in terms of the state of the art at the turn of the century. However, it has been amply demonstrated that for a given sampling station and initial pressure, the separating calorimeter does remove the greater part of the moisture present.

Calibration instructions for some of the early instruments (2) called for comparing the performance of the unit under test conditions and on "dry steam." The latter was considered to be obtainable from a boiler drum during very low load, or from a header in which the steam velocity was nearly zero. In either case the implication was that the water droplets in the wet steam were heavy enough to settle out.

The advent of the combined separating—throttling calorimeter (3) should have upset the large droplet theory. Some liquid must have been able to pass through the separating element, or the temperature reading on the throttling unit would have been too high. In a most interesting paper by Upton (4), he investigated the ability of flowing steam to carry small spheres of water. For the approach velocities found in calorimeters these spherical droplets can be surprisingly large.

The present paper reports upon the possible combinations of paths by which wet steam may travel through a throttling calorimeter. The assumptions and approach would be equally valid for other devices in which steam undergoes an expansion and a drying process.

Theory

A plan view of a simple throttling calorimeter is shown in Fig. 1. The steam pipe (1) has a sampling tube, A, a pressure gage connection, B, and external insulation. A valve, C, connects the sampling tube and the pipe, D, in the end of which there is an orifice, E. Steam expands through E into the calorimeter chamber (2). A thermometer, T, measures the stagnation temperature of the spent steam; a pressure gage connection is available at F. The calorimeter chamber and connecting piping are heavily insulated, and often the former is highly polished.

For purposes of analysis the following nomenclature will be used:

A = area, sq ft
C = constant
d = diameter of droplet, ft
D = diameter, ft
F = force, lbs
h = enthalpy, Btu/lb
J = 778.26 ft-lbs/Btu
KE = kinetic energy, ft-lbs
L = length, ft
m = moisture, per cent
p = pressure, psia
Q = heat, Btu
r = radius, ft
S = surface tension, lbs/ft
T = temperature, F
u = internal energy, Btu/lb
v = specific volume, ft³/lb
w = work, Btu
x = quality, per cent
y = distance, ft
z = height above a datum, ft
ρ = density, mass per unit volume; ρ_f liquid; ρ_g vapor

* Member, ASME Sub-Committee (F), Power Test Codes Committee No. 19, on Instruments and Apparatus.
[1] Numbers in parentheses refer to Bibliography at the end of the article.

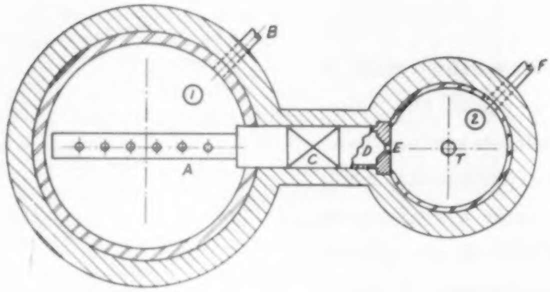


Fig. 1—Plan view of throttling steam calorimeter

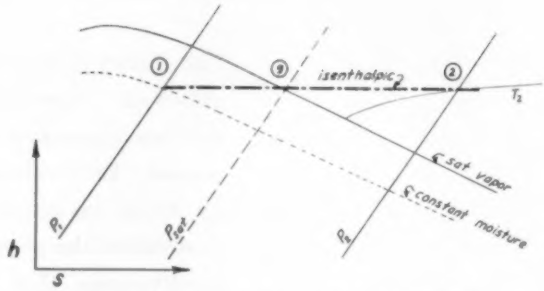


Fig. 2—Constant enthalpy path in the h-S plane

μ = viscosity coefficient
ν = kinematic viscosity

For one pound of a heat medium, the steady flow energy equation, in consistent units, is given by:

$$Z_1 + P_1v_1 + u_1 + (KE)_1 + Q = Z_2 + P_2v_2 + u_2 + (KE)_2 + W \quad (1)$$

When applied to a throttling calorimeter, the potential and kinetic energies become negligibly small. There is no "paddle wheel" work, and the ideal instrument is also adiabatic. Equation (1) therefore reduces to:

$$P_1v_1 + u_1 = h_1 = P_2v_2 + u_2 = h_2 \quad (2)$$

Equality of the terminal enthalpy values does not in itself make the calorimeter usable. In order to establish the inlet enthalpy it must be possible to measure that at exhaust. This requirement is met only when the endpoint lies in the superheat region, where the enthalpy is uniquely set for a given pressure and temperature.

In Fig. 2 an isenthalpic path is shown in the h-s plane, extending from the point 1 in the wet region, to the point 2 in the superheated region. Such a path might be followed during the very slow expansion of wet steam through a porous plug. In that case complete thermal equilibrium would be established during each decrease in pressure.

Although it is customary to draw a horizontal line across the Mollier chart to find steam quality from calorimeter measurements, the method is valid only for determining the endpoints. The actual steam path in the calorimeter cannot be isenthalpic.

In Fig. 3 a constant enthalpy path is traced out in the T-S plane. The points 1-g-2 correspond to the equivalent stations on the h-s diagram in Fig. 2. The extent of irreversibility in throttling is nicely demonstrated in Fig. 3. All of the area under the constant pressure path to 1 represents the enthalpy at 1. For each succeeding step along the isenthalpic, the total area under the isobar on the T-S plane must be the same. This is done at the expense of the availability of the energy, as evidenced by lower temperature, and pressure, and is reflected in the increase in entropy.

Returning to Fig. 1, is it possible to realize the physical steps assumed to take place in the calorimeter? Passage from 1 to 2 by a series of reversible paths is shown as 1-A-2 in Fig. 4 for the h-s plane and in Fig. 5 in the T-S plane. Here it has been assumed that the steam expands isentropically in the orifice and that a subsequent constant pressure drying and superheating process follows.

Experience with real orifices rules out the possibility of isentropic expansion even with dry steam. If the orifice actually handles a two-phase mixture with water droplets entrained in dry steam, the mechanism of entrainment would itself be irreversible.

It is probable then, that the expansion of the steam follows an irreversible path such as 1-B-2. in Fig. 4. The same processes are identified as end points in Fig. 5, recalling that irreversible paths cannot be drawn in the T-S plane.

Is it possible that the steam reaches the dry saturated vapor state at the exit of the orifice? Such a path would be shown as 1-g-2 in Fig. 4. That this is extremely unlikely will be shown later.

An idealized picture of the two phase flow through the orifice is shown in Fig. 6. Here it is assumed that dry saturated steam is the vehicle by which small spherical droplets of water are moved through the orifice. The arbitrary dimensions of the orifice are diameter D, and length L. The droplet size, d, may be considered to be small in comparison to the orifice diameter and the droplet need not be limited to movement along the centerline of the orifice. For purposes of discussion the diameter of the spherical droplet has been pictured as smaller leaving the orifice than at entrance.

It has been shown (4) that, within the ranges of Reynold's numbers encountered in steam lines, two forces resist the movement of a sphere in a fluid medium. That due to eddy resistance may be expressed in the form:

$$F_e = C\rho(d)^2(V)^2 \quad (3)$$

The second resisting force is due to viscous drag, and is given by Stokes' equation:

$$F_v = 3\pi\mu(d)(V) \quad (4)$$

The total resisting force is then:

$$F_t = 3\pi\mu(d)(V) + C\rho(d)^2(V)^2 \quad (5)$$

When the spherical body is a drop of liquid, a question arises as to whether the drop will break up under the action of the forces at work. The strength of a sphere of liquid is a function of the circumference and the surface tension. However, this problem is further complicated by the fact that, under stress, the droplet deforms, taking on a pear shape prior to breaking apart.

As a first approximation it may be assumed that the deformed sphere breaks off at a circumference about half as large as that of the original sphere. The strength of the drop may then be estimated as:

$$\frac{\pi}{2}(d)(S) \quad (6)$$

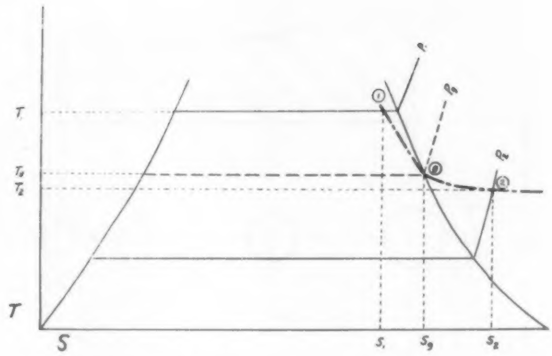


Fig. 3—Constant enthalpy path in the T-S plane; steam initially wet and finally superheated

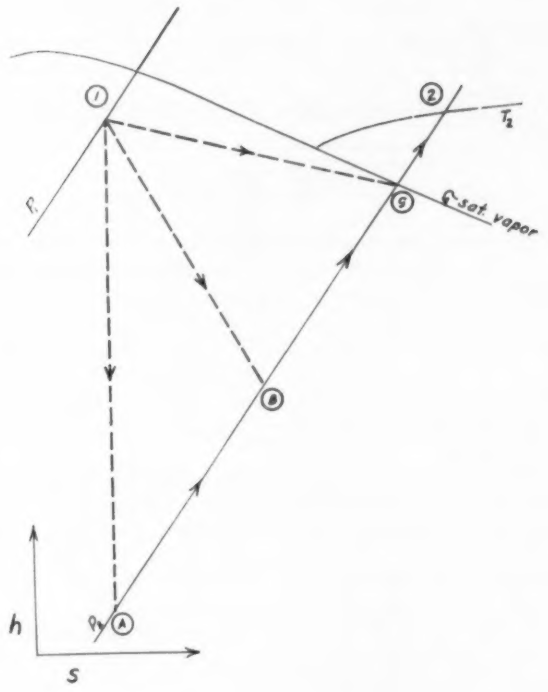


Fig. 4—Mollier diagram showing alternate paths by which wet steam is throttled and dried

The limiting velocity which a drop may attain without breaking up is determined by equating the strength and the resisting forces:

$$\frac{\pi}{2}\,(d)(S) = 3\pi\mu(d)(V_t) + C\rho(d)^2(V_t)^2 \qquad (7)$$

In equation (7) V_t represents the "tearing velocity," the limiting velocity at which the total resistance to motion is equal to the strength of the droplet.

It can be shown that under viscous forces alone, the droplet would tear only at very high velocities. Eddy resistances would become predominant before the viscous tear velocities were attained. Equation (7) may be solved approximately without the viscous term, giving

$$V_t = \sqrt{\frac{\pi S}{2C\rho d}} \qquad (8)$$

The tendency of the water droplet to settle out of the steam stream is related to diameter. The mass of the drop is given by:

$$\frac{\pi}{6}\,(d)^3\rho_f$$

Equating the droplet weight and the resisting forces:

$$\frac{\pi}{6}\,(d)^3g[\rho_f - \rho_g] = 3\pi\mu(d)(V_f) + C\rho_g(d)^2(V_f)^2 \qquad (9)$$

where V_f is the falling velocity.

If again the eddy resistance is predominant, equation (9) may be reduced to:

$$V_f = \sqrt{\frac{\pi dg[\rho_f - \rho_g]}{6C\rho_g}} \qquad (10)$$

A limiting condition exists when the tearing and falling velocities are equal. Equations (7) and (9) are then equated and:

$$\frac{\pi}{6}(d)^3g[\rho_f - \rho_g] = \frac{\pi}{2}\,(d)(S)$$

$$d = \sqrt{\frac{3S}{g[\rho_f - \rho_g]}} \qquad (11)$$

Equation (11) gives the maximum drop diameter that can be maintained against the pull of gravity. Any gain in velocity in either the vertical or horizontal direction will result in a breaking up of the droplet.

A further effect is that of entrainment or atomization of droplets standing on the edges of line internals. Using equations (3) through (11), it can be shown that, for the usual approach velocities, rather large droplets can be carried to the calorimeter orifice. Also, as the velocity decreases, the size of drop that can be atomized increases. These data are presented in Table I.

Returning to Fig. 6, is there a tendency for the droplet to "explode" as it moves along the axis of the orifice into progressively lower stream pressures? An approximate solution may be obtained by assuming that the drop diameter is small enough to be transported at the given station in the orifice according to equation (7). Under these conditions the accelerating force on the sphere becomes negligibly small, and the stability of the droplet can be approximated by equating the pressure differential

TABLE I—MAXIMUM DROP DIAMETER AS INFLUENCED BY PRESSURE AND VELOCITY

Steam pressure, psia	200			100		
Steam velocity, ft/sec	130	65	33	100	50	25
Drop diameter, in., carried against gravity	0.149	0.149	0.149	0.158	0.158	0.158
Drop diameter, in., atomized	0.001	0.006	0.019	0.006	0.019	0.084

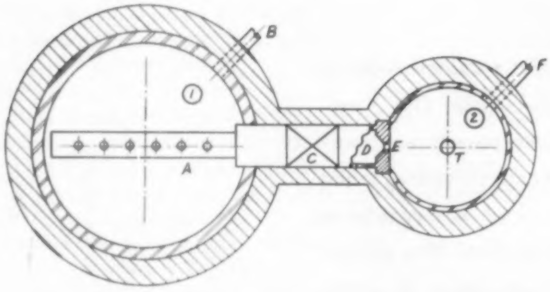
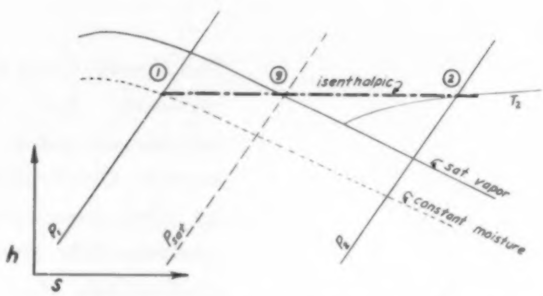


Fig. 1—Plan view of throttling steam calorimeter



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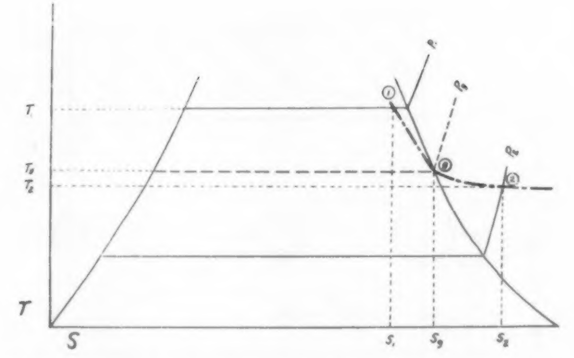

Fig. 3—Constant enthalpy path in the T-S plane; steam initially wet and finally superheated

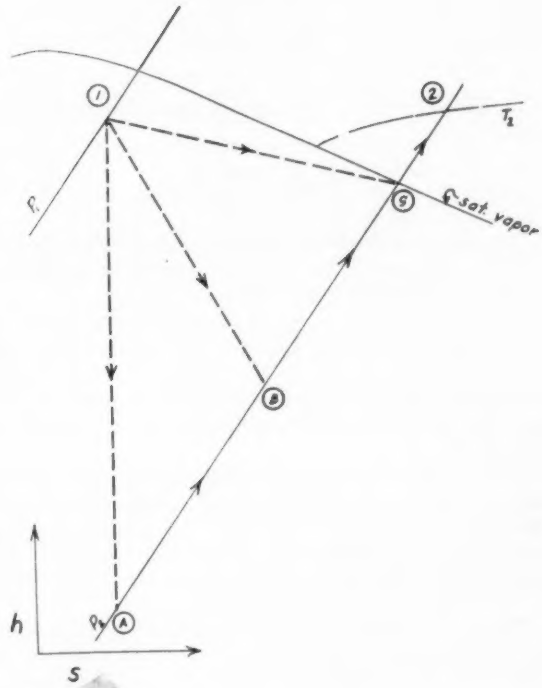

Fig. 4—Mollier diagram showing alternate paths by which wet steam is throttled and dried

The limiting velocity which a drop may attain without breaking up is determined by equating the strength and the resisting forces:

$$\frac{\pi}{2}(d)(S) = 3\pi\mu(d)(V_t) + C\rho(d)^2(V_t)^2 \qquad (7)$$

In equation (7) V_t represents the "tearing velocity," the limiting velocity at which the total resistance to motion is equal to the strength of the droplet.

It can be shown that under viscous forces alone, the droplet would tear only at very high velocities. Eddy resistances would become predominant before the viscous tear velocities were attained. Equation (7) may be solved approximately without the viscous term, giving

$$V_t = \sqrt{\frac{\pi S}{2C\rho d}} \qquad (8)$$

The tendency of the water droplet to settle out of the steam stream is related to diameter. The mass of the drop is given by:

$$\frac{\pi}{6}(d)^3\rho_f$$

Equating the droplet weight and the resisting forces:

$$\frac{\pi}{6}(d)^3 g[\rho_f - \rho_g] = 3\pi\mu(d)(V_f) + C\rho_g(d)^2(V_f)^2 \qquad (9)$$

where V_f is the falling velocity.

If again the eddy resistance is predominant, equation (9) may be reduced to:

$$V_f = \sqrt{\frac{\pi d g[\rho_f - \rho_g]}{6C\rho_g}} \qquad (10)$$

A limiting condition exists when the tearing and falling velocities are equal. Equations (7) and (9) are then equal, and:

$$\frac{\pi}{6}(d)^3 g[\rho_f - \rho_g] = \frac{\pi}{2}(d)(S)$$

$$d = \sqrt{\frac{3S}{g[\rho_f - \rho_g]}} \qquad (11)$$

Equation (11) gives the maximum drop diameter that can be maintained against the pull of gravity. Any gain in velocity in either the vertical or horizontal direction will result in a breaking up of the droplet.

A further effect is that of entrainment or atomization of droplets standing on the edges of line internals. Using equations (3) through (11), it can be shown that, for the usual approach velocities, rather large droplets can be carried to the calorimeter orifice. Also, as the velocity decreases, the size of drop that can be atomized increases. These data are presented in Table I.

Returning to Fig. 6, is there a tendency for the droplet to "explode" as it moves along the axis of the orifice into progressively lower stream pressures? An approximate solution may be obtained by assuming that the drop diameter is small enough to be transported at the given station in the orifice according to equation (7). Under these conditions the accelerating force on the sphere becomes negligibly small, and the stability of the droplet can be approximated by equating the pressure differential

TABLE I—MAXIMUM DROP DIAMETER AS INFLUENCED BY PRESSURE AND VELOCITY

Steam pressure, psia	200			100		
Steam velocity, ft/sec	130	65	33	100	50	25
Drop diameter, in., carried against gravity	0.149	0.149	0.149	0.158	0.158	0.158
Drop diameter, in., atomized	0.001	0.006	0.019	0.006	0.019	0.084

TABLE II—TYPICAL DROP DIAMETERS USING EQUATION (13)

Pressure psia	200	100
Surface tension lb/ft	0.00276	0.00322
Drop diameter, in.	$0.025 \times (10)^{-4}$	$0.063 \times (10)^{-4}$

on the projected area of the sphere to the strength of the sphere:

$$\frac{\pi}{4}(d)^2(\Delta P) = \frac{\pi}{2}(d)(S) \qquad (12)$$

The diameter of sphere that could withstand the full pressure differential between the steam line and the calorimeter chamber would be:

$$d = \left[\frac{2S}{P_1 - P_2}\right] \qquad (13)$$

For representative initial steam conditions, drop diameters have been computed from equation (13) and listed in Table II

From Table II it is apparent that only very small droplets are able to withstand the pressure differential across the throttling orifice. Admittedly, this analysis is a first approximation. However, an analogous case has been investigated experimentally in which drop sizes in a steam nozzle were actually measured.

Yellott (5) studied the formation of water droplets in expanding steam in the vicinity of the Wilson zone. He used a glass-walled nozzle and observed the light emerging from the apparatus when an intense source of white light was beamed along the axis of the nozzle. Rayleigh's equation for the intensity of light scattered by small spheres is given as:

$$I = k\frac{r^6}{\lambda^4}\left[1 + \cos^2\beta\right] \qquad (14)$$

where:

k = constant

r = radius of sphere

λ = wave length of light

β = angle between line of observation and incident light beam

From his observations on the color and intensity of the scattered light, Yellott deduced that the mean drop radius was $6.2 \times (10)^{-8}$ cm, corresponding to a mean drop diameter of $4.88 \times (10)^{-8}$.

For these small droplets it was found that there was no "explosion" of the sphere as it moved into the low pressure end of the nozzle. In one test the drop size remained constant throughout the expansion. In another

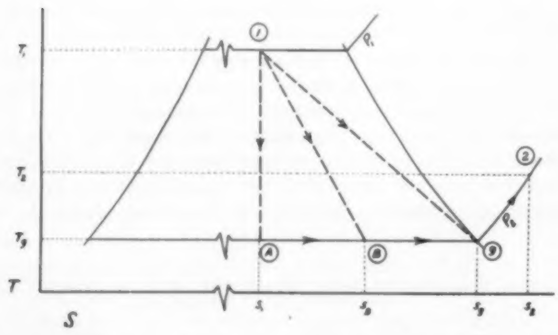

Fig. 5—T-S plane showing same paths as Fig. 4. Abscissa has been shortened to emphasize area of paths

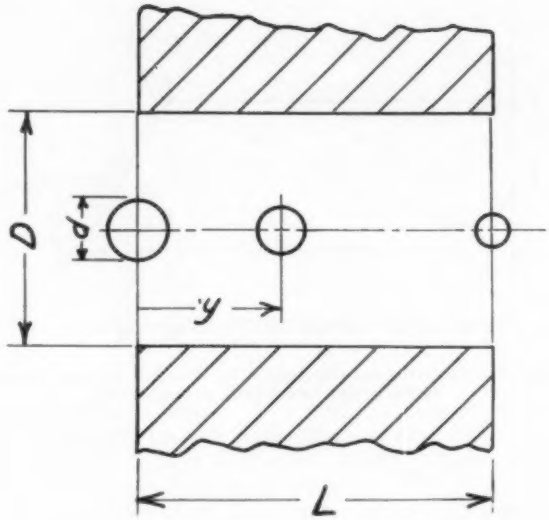

Fig. 6—Spherical water droplet traversing constant diameter orifice

experiment he showed that the drop size actually grew during the passage through the nozzle from a diameter of $7.86 \times (10)^{-8}$ in. to $4.74 \times (10)^{-5}$ in.

Having considered the stability of the droplet in terms of resistance to tearing, falling, and pressure differential, what of the tendency to evaporate in transit? In Fig. 7 the T-S diagram is shown for the liquid phase alone. The droplet approaches the orifice at the Pressure P_1 as saturated liquid. The enthalpy of the liquid is shown as the shaded area under the curve from 492° R to f_1. Throttling does not alter the enthalpy, and the point A, at the lower pressure P_2, is located so that the area under $492\text{-}f_2\text{-}A$ is the same as that under $492\text{-}f_1$. The saturated liquid enthalpy at the lower pressure is represented by the area under $492\text{-}f_2$.

The droplet which has undergone throttling has an excess of enthalpy above that of saturated liquid at the lower pressure. This is shown as the area under $f_2 - A$. However, in no case will the point A coincide with the point C, saturated vapor. There is not enough thermal energy in the liquid droplet to cause vaporization at the lower pressure. The deficiency in enthalpy for a unit mass is given by:

$$h_{g2} - h_{f1} = [h_{fg2} - (h_{f1} - h_{f2})] \qquad (15)$$

In terms of heat energy above, the droplet could undergo partial vaporization to the extent of:

$$\left[\frac{h_{f1} - h_{f2}}{h_{fg2}}\right]$$

Discussion

1. Based upon force analyses on a droplet in a steam line, expressions for the tearing and falling velocities have been cited. For the operating conditions found in calorimeter practice, droplets may be conveyed which may be of the order of magnitude of the orifice diameter.

2. Along the axis of the orifice, the tendency of the water particle to break up due to pressure differential becomes the controlling factor. Only very small droplets can pass through the orifices.

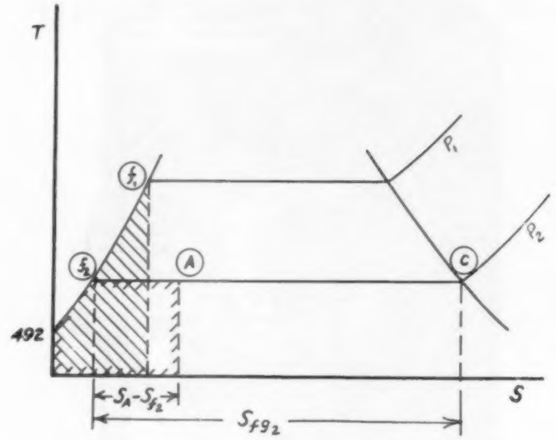

Fig. 7—T-S diagram for liquid phase alone

3. The experiments of Yellott showed that very small droplets, formed at the Wilson Zone, were carried through a steam nozzle. In at least one case he reported a growth of the droplet as it traversed the low pressure end of the nozzle. In terms of calorimeter practice (2) and (3) confirm the fact that water particles do leave the orifice.

Referring to Fig. 4 and 5, the path 1-g-2 cannot be realized, as both the analysis and experimental data show. Graphical evidence is available in the "steam tables" (6). The insert following page 82 is a temperature-entropy chart on which the constant enthalpy lines have been drawn. None of the isenthalpics, starting at saturated liquid, terminates anywhere near saturated vapor at one atmosphere. The existence of water droplets at the orifice exit tends to substantiate the theory that the sequence of steps is 1-B-2. The probable location of the point B could be estimated by assuming a nozzle efficiency for the orifice and considering both liquid and vapor phases (7).

4. The terminal superheating of the low pressure steam must be due to the dissipation of the kinetic energies of the steam and water droplets, as this is the only energy source available.

BIBLIOGRAPHY

(1) "New Form of Steam Calorimeter," R. C. Carpenter, *Tr. A.S.M.E.*, vol. 17, 1896, pp. 608–624.

(2) "Experimental Mechanical Engineering," H. Diederichs and W. C. Andrae, Volume I, pp. 440–466, John Wiley and Sons Inc., New York, 1930.

(3) "Test of a 15,000 KW Steam-Engine-Turbine Unit," H. G. Stott and R. J. S. Piggott, *Tr. A.S.M.E.*, vol. 32, 1910, pp. 76–77.

(4) "Raindrops and Engineering," G. B. Upton, *Sibley Journal of Engineering*, vol. XXXVII, Jan. 1923, pp. 2–9.

(5) "Supersaturated Steam," J. I. Yellott, *Tr. A.S.M.E.*, vol. 56, 1934, pp. 411–430.

(6) "Thermodynamic Properties of Steam," J. H. Keenan and F. G. Keyes, Fig. 9, p. 83, John Wiley and Sons Inc., New York, 1954.

(7) "Supersaturation and the Flow of Wet Steam," G. A. Goodenough, *Power*, vol. 66, 1927, pp. 466–469.

The Growth of Sonics in Industry*

By ROBERT L. ROD, Acoustica Associates, Inc.

FIFTEEN years ago the sonics industry as we know it today was virtually non-existent. With the exception of Sonar apparatus and fathometers, practically no equipment utilizing sonic energy for either gaining information or for performing useful work was available to the industrial market. The studies being conducted in the field were for the most part carried out by educational institutions with limited budgets, and, for the most part, any practical results were completely ignored by industry.

Today, the situation is quite different. The members of the Ultrasonic Manufacturing Association alone manufacture equipment estimated at between \$15,000,000 and \$25,000,000 sales annually, excluding military-type sonar equipment.

In general, it is interesting to consider the types of sonics equipment in terms of those which either are used to gain information or to perform useful work and further to show which are presently available (shall we say "off the shelf" items) and those which undoubtedly will be obtainable in the near future. The Workshop Committee has defined these products as follows:

For Gaining Information

A. *Available Now*—Non-destructive Testing; Liquid Level Sensors; Delay Lines; Filters; Viscosimeters.

B. *Future*—Flowmetering; Communication—a. Paging, b. Remote Control, c. Underwater.

For Useful Work

A. *Available Now*—Drilling; Grinding; Cleaning; Oil Well Drilling; Degassing; Emulsification; Barnacle Inhibition; Inchworm; Soldering & Welding; Heat Transfer Improvement; Boiler Scale Inhibition.

B. *Future*—Plating; Flotation; Impregnation; Particle Precipitation; Pickling; Quenching; Etching.

For the most part, present installations of ultrasonic cleaning require some degree of hand-tailoring with respect to equipment and actual acoustic techniques involved. In liquid level control we can expect to see greater use of such devices as the unique ultrasonic level sensor and of sonar-type continuous level gages, particularly in missile work, tank gaging in the chemical, food, plastic and petroleum storage market. In the field of metal working, ultrasonic drills, grinders and friction-reducing devices, as well as non-destructive testers, are becoming an integral part of routine manufacturing processes.

In conventional and atomic power plant and in nuclear work, sonics and ultrasonics are playing an increasingly important role in radioactive decontaminating, degassing of reactor fluids or boiler feed water, aerosol agglomeration for byproduct recovery or smog control and emulsification processes. Heat transfer is improved by acoustic vibrations while deposition of boiler or chemical scale and precipitates on walls of tanks or in tubes is retarded by the same techniques.

* Abstracted from a paper presented at 1957 Acoustical Society of America Meeting, Barbizon-Plaza Hotel, New York, May 23, 1957.

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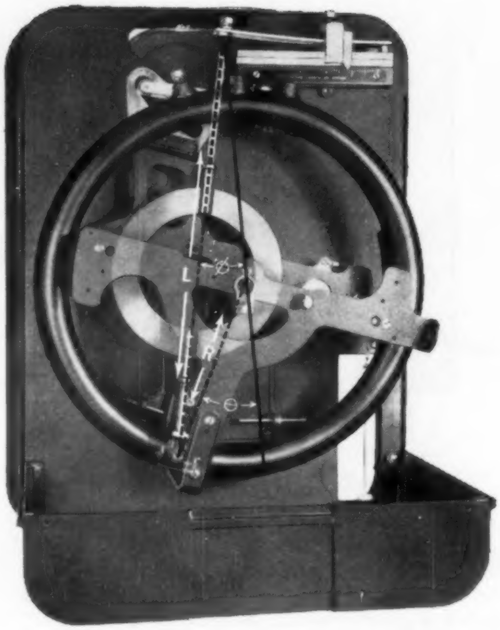

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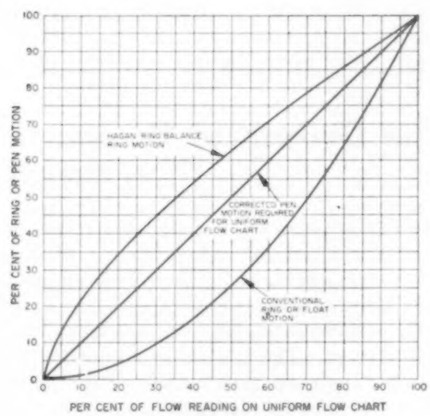

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$$\text{Spring deflection} = R(1-\cos\theta) - L(1-\cos\phi),$$

and is graphically illustrated at the right. The upper curve shows that the ring motion at low range exceeds the requirement to produce pen motion linear with flow. Thus, the cam which transmits ring motion to the pen arm can convert this excess ring motion into extra power for precise pen movement.

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Air Pollution Control Association Celebrates Its Fifteenth Anniversary

JUNE 2–6 the Air Pollution Control Assn., formerly the Smoke Prevention Assn. of America, met in St. Louis to celebrate its Golden Anniversary. For the first time the Association assigned individual sessions to major engineering societies for sponsorship. Those societies participating were the American Society of Heating and Air Conditioning Engineers, the American Institute of Chemical Engineers, the American Meteorological Society, the ASME, and, of course, the APCA.

Honors and Awards

Four outstanding men in the field of Air Pollution Control were honored: **Raymond R. Tucker,** Mayor of St. Louis, the Mellon Award; **Walter A. Schmidt** of Los Angeles, the Chambers Award; **Henry Hebley** of Pittsburgh and **William G. Christy** of New York City, Honorary Memberships.

Mayor Raymond R. Tucker of St. Louis was the principal banquet speaker. In his opinion a successful air pollution program can help trigger a complete renaissance of cities. The history of smoke elimination in St. Louis was a case in point.

In the Fall of 1930, Mayor Tucker pointed out, St. Louis experienced one of the worst smoke palls in its history. Visibility was reduced to a few feet. Critics of the anti-smoke program had a field day. But as a result the citizenry were spurred on into providing greater support for the program, and the passing of a city ordinance with "teeth" in it, controlling the burning of high volatile fuel with mechanical fuel equipment to burn it smokelessly, and the prevention of use of such fuel by those who did not use such equipment.

St. Louis and Pittsburgh were once regarded as the smokiest and dirtiest cities in the nation. The critics said these cities were decaying and dying, while others were expanding and improving. Clearing the air has triggered a revitalization of both Pittsburgh and St. Louis.

Technical Papers

J. H. Field, L. W. Brunn, W. P. Haynes and **H. E. Benson,** U. S. Bureau of Mines, presented a paper on "Cost Estimates of Liquid-Scrubbing Processes for Removing Sulfur Dioxide from Flue Gases." At present three liquid-scrubbing processes, using limestone, ammonia, or sodium sulfite as the reactant, have been developed either commercially or on a pilot-plant scale to remove sulfur dioxide from flue gases. To determine the up-to-date economics of these three processes, capital and operating costs have been estimated for removal of sulfur dioxide from stack gases of a power plant of 120,000 kw capacity burning coal of 1.5 or 5 per cent sulfur content. The raw-material and utility requirements, production of by-products and waste materials, and operating costs for removing 70 and 90 per cent of the sulfur dioxide are shown. Capital costs, including working capital, range from about 2 to 5 million dollars for the different processes at the assumed inlet and outlet concentrations of sulfur dioxide; operating costs range from 0.5 to over 1 mill per kilowatt hour of power after credits have been allowed for by-products.

"The Fulham–Simon-Carves Process for the Recovery of Sulfur from Flue Gases" was presented by **T. Kennaway** of Simon-Carves Ltd. In 1938, the Metropolitan Borough of Fulham approached Simon-Carves Ltd. and asked them if they could develop a process for manufacturing ammonium sulfate from flue gases, and put forward a pilot plant design.

The process proposed by Simon-Carves consisted essentially of scrubbing the flue gases with ammonia liquor derived from gas works or coke oven plants to produce a solution of ammonium sulfate, sulfite, bisulfite and thiosulfite, and which, by a process of autoclaving could then be converted into ammonium sulfate and sulfur.

In 1954, the Central Electricity Authority, who had reviewed the process, decided to proceed with the construction of a plant on the half-boiler scale similar to that envisaged for Fulham. The site chosen was at North Wilford Power Station, Nottingham.

The plant has been designed to handle 56,000 cfm (actual) of the flue gases produced by the combustion of coal having a sulfur content of up to 3 per cent. It was estimated that if the liquor composition in the scrubber is similar to that obtained at Fulham up to 11 tons of ammonium sulfate and 2000 lb of sulfur should be produced from this plant daily, by working it continuously. The pilot plant is therefore of such a size that it should enable satisfactory cost estimates for a full scale plant to be drawn up from the results. It will also afford an opportunity to find out the best operating conditions and to confirm the design of the units.

Harlan W. Nelson and **Carl J. Lyons,** Battelle Memorial Institute, contributed a paper, "Sources and Control of Sulfur-Bearing Pollutants." It was estimated in the mid 1940's that almost 40 million tons of sulfur were being emitted annually into the world's atmosphere from the combustion of coal, the smelting of ores, and the production and consumption of petroleum and natural gas. This amount must now be exceeded by a significant margin, since the world production and consumption of the raw materials concerned has increased, and since there is some evidence that the average sulfur content of fuels is also increasing. Although the volume of sulfur compounds, chiefly sulfur dioxide, represented by this release of sulfur is enormous, the volume of air in the atmosphere is so much larger that there is little danger of raising the average concentration of sulfur dioxide to a level detrimental to man or his environment if uniform dilution were possible. It is in the special circumstance of sulfur emission where higher concentrations are brought about by reason of geographical and meteorological conditions that detrimental effects are observed. Also, the sulfur dioxide does not remain in the air but reaches the earth eventually in other forms.

Sulfur dioxide, sulfur trioxide and hydrogen sulfide are the three principal sulfur-containing pollutants. By far the greatest proportion of the sulfur compounds emitted to the atmosphere is in the form of sulfur dioxide. This form is produced from the smelting of ores of metals such as zinc, lead, copper and nickel, from the combustion of gases from refinery

and natural gas waste products, and from the combustion of oil and coal.

As an example of the problem of pollution offered by a coal burning power plant, the authors considered one which discharges 1,000,000 cfm of flue gas having an average concentration of approximately 0.28 per cent by volume of SO_2. This represents an emission of roughly 190 tons per day of SO_2. These figures indicate the magnitude of the problem when considering sulfur emission from coal-burning equipment. The fact that the concentration of SO_2 in the effluent gas is considerably below 1 per cent presents a challenging technological problem in attempts to reduce sulfur emissions.

At the present time there is only one process, installed at two power stations, in use for the treatment of effluent gases from large boilers burning coal. The process was first installed at the Battersea Power Station in London, and is termed the Battersea process. This installation and the one at the Bankside Station in London were put in as a result of public opinion in England in 1929 following a series of exceptionally severe smogs. The original Battersea installation treated the effluent gas from coal burned with an average sulfur content of 0.88 per cent in such a fashion that only 9 per cent of the sulfur escaped into the atmosphere. The process is relatively simple and takes advantage of the fact that the River Thames, which supplies the water for scrubbing the flue gases, already contains most of the alkali that is required to neutralize the sulfur dioxide in the effluent gases. In addition, the river carries away the product, calcium sulfate, in solution. Thus, use of the process was favored by natural conditions.

The Howden I.C.I. cyclic lime process was tried for a time at the Tir John Power Station in Swansea, Wales, England, and at the Fulham Power Station in London. Essentially, this is a cyclic process similar to that used at the Battersea Power Station except that in this process calcium carbonate is concentrated and discharged as a wet mud. The scrubbing solution is essentially the same as used at Battersea, a slurry of the cheapest alkalies, chalk and lime. It has been estimated that use of the process would cost about 25 per cent of the cost of the coal consumed at a large central station power plant. In this process as well as the one at Battersea the SO_2 is not recovered in saleable form. Most other development work has been directed towards processes which would yield a commercial product as an operating credit.

The possibility of producing sulfuric acid, either concentrated or dilute, directly from SO_2-containing power plant gases has been investigated. Johnstone, as part of a long-range program on the removal of SO_2 from such flue gases, studied the catalytic oxidation of SO_2 absorbed in water to produce sulfuric acid. He found that iron and manganese increased the rate of oxidation of SO_2 in solution and that dilute sulfuric acid could be made. Although 40 per cent acid was made for short periods of time, the action of the catalyst was soon inhibited by phenols and copper scales. Recent work has extended this study to include the use of ozone to oxidize the SO_2. It was shown that flue gases containing 0.35 per cent by volume of SO_2 could be treated with air containing ozone and then scrubbed with a dilute solution of H_2SO_4. The cost of the ozone required per ton of recovered H_2SO_4 was estimated to be $5.00.

When all has been considered regarding the problem of controlling the undesirable effects of discharging waste or stack gases containing sulfur dioxides into the atmosphere, only a limited number of possible remedies can be listed. This list would include:

(1) The direct approach. This would involve the removal of significant reduction of the sulfur content of medium-high-sulfur fuels. This is technically possible—within limits—for both fuel oil and coal, but only at appreciably increased cost. Many fuel engineers and coal producers have long argued that the use of cleaned coal at the larger power and utility plants would lead, in the end, to decreased outage and maintenance costs. Lowering of the ash content is of chief consideration in this instance, but reduction of the sulfur content is also a consideration. However, it is generally the practice for these power plants to purchase coal on a basis of direct cost per unit heating value and of minimum freight costs, in the conviction that the equipment can then produce steam at the lowest overall cost.

Again, for economic and logistic reasons, legal restriction of sulfur contents could not be the answer for the country as a whole.

(2) More efficient dispersion of effluent gases into the atmosphere. High stacks have helped in this regard, but there is a practical limit to the height of stacks, and the topographical and meteorological conditions at some locations are such that increasing the stack height to any practical degree would not help the situation under adverse conditions.

(3) The addition of chemical materials to the fuel to fix the suflur in

solid form. This has been suggested from time to time, but no practical result is known to have been achieved. Inorganic materials have been added to the fuel or in the furnace to assist in the control of boiler deposits and external tube corrosion, but the fixation of sulfur has not been accomplished to a practical degree.

(4) There is, finally, the possibility of washing or treating the stack gases to remove the sulfur oxides before the gases are discharged to the atmosphere, as discussed in some detail in the preceding paragraphs.

The final conclusion must be that none of the methods represent a final practical and economic answer to the nationwide problem of controlling sulfur emissions from stack gases. Any of the suggested solutions will add an increment of cost to the final cost of the steam generated or the electrical power produced. In the final analysis, whatever the solution, the costs of eliminating or minimizing the effect of the sulfur oxides in stack gases would be passed on to the consumer. If the public demands a solution to the problem, they must do so with realization that higher costs are involved and that additional costs will be passed on to them.

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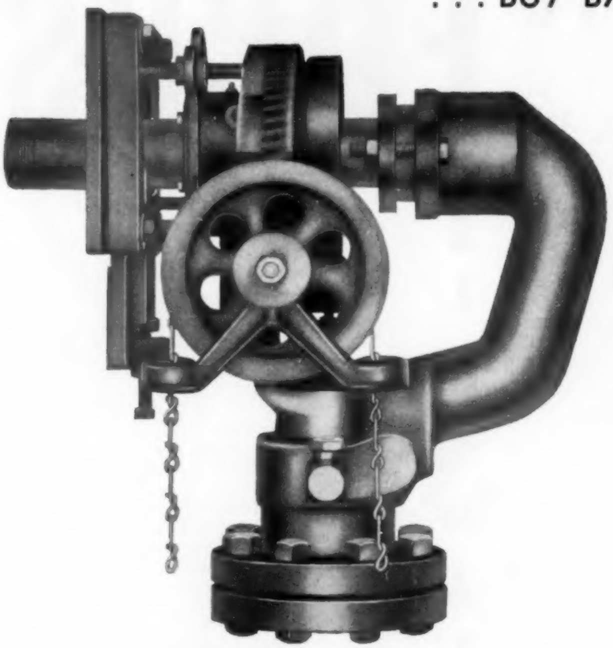

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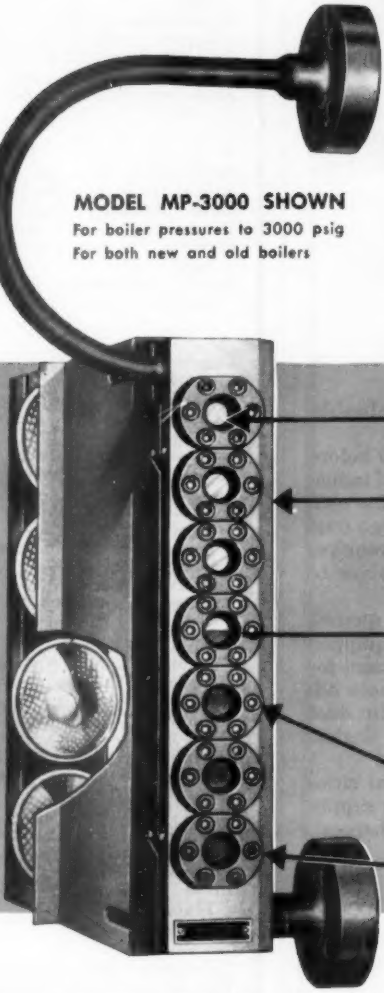

Also available is Model MP-900 for boiler pressures to 900 psig

Because the Diamond Multi-Port solves the problems inherent in water level gauges on boilers operating at high temperatures and pressures, it has had rapid and wide acceptance. In addition to the 1400 for central station generating plants, more than 150 have been sold to industrial power plants.

Advantages of the Multi-Port are many. In addition to those shown above, it has maximum thermal stability for rapid starting . . . "Hi-Lite" illuminator for improved readability . . . welded construction for permanent tightness . . . end stems can be furnished instead of flanges . . . startling reductions in maintenance costs.

Write for Bulletin 1174V (Model MP-3000) or Bulletin 2044V (Model MP-900) for more information.

7801

Diamond

DIAMOND POWER SPECIALTY CORP.

LANCASTER, OHIO • DIAMOND SPECIALTY LIMITED — *Windsor, Ontario*

Advertisers' Index

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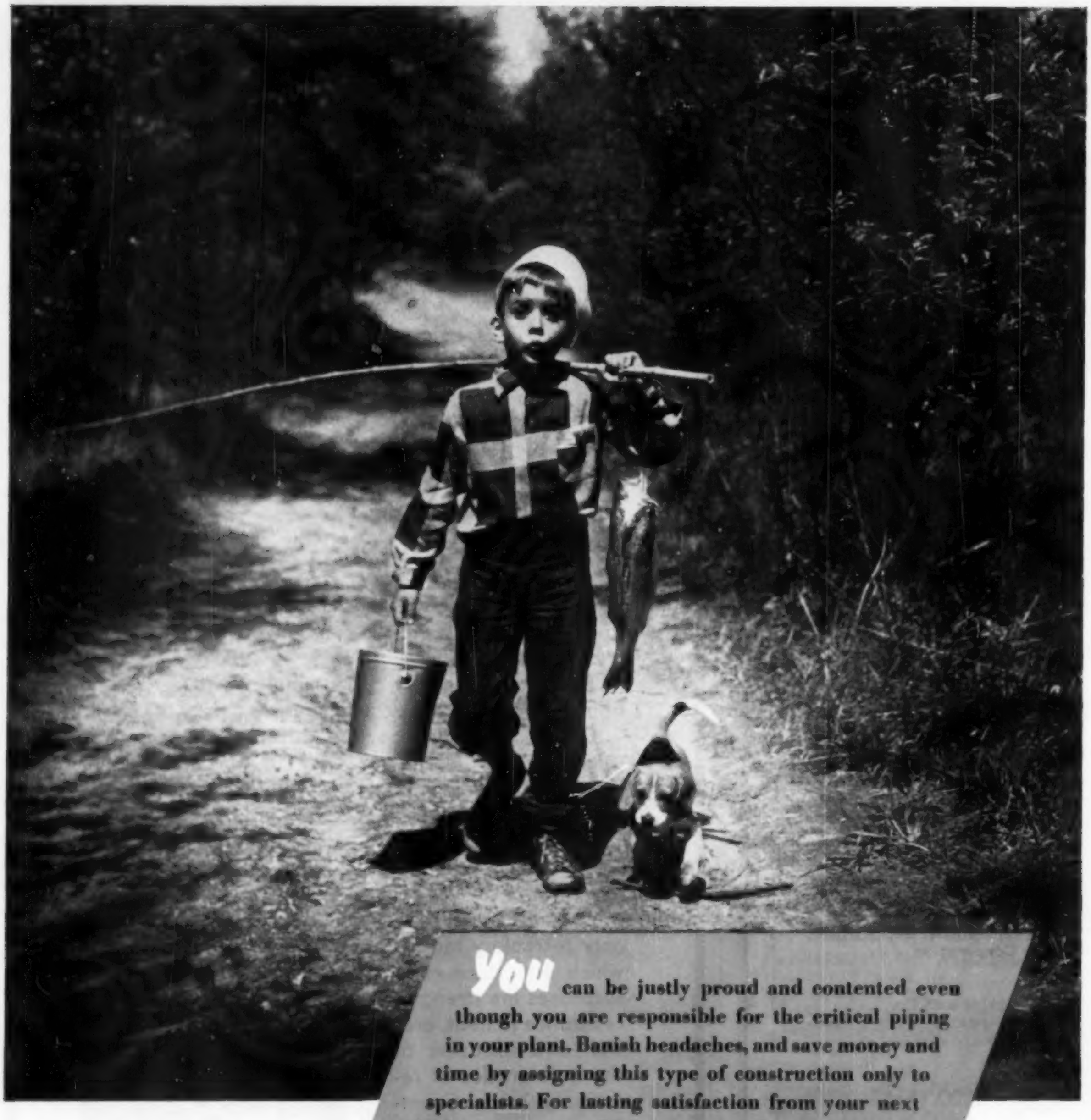
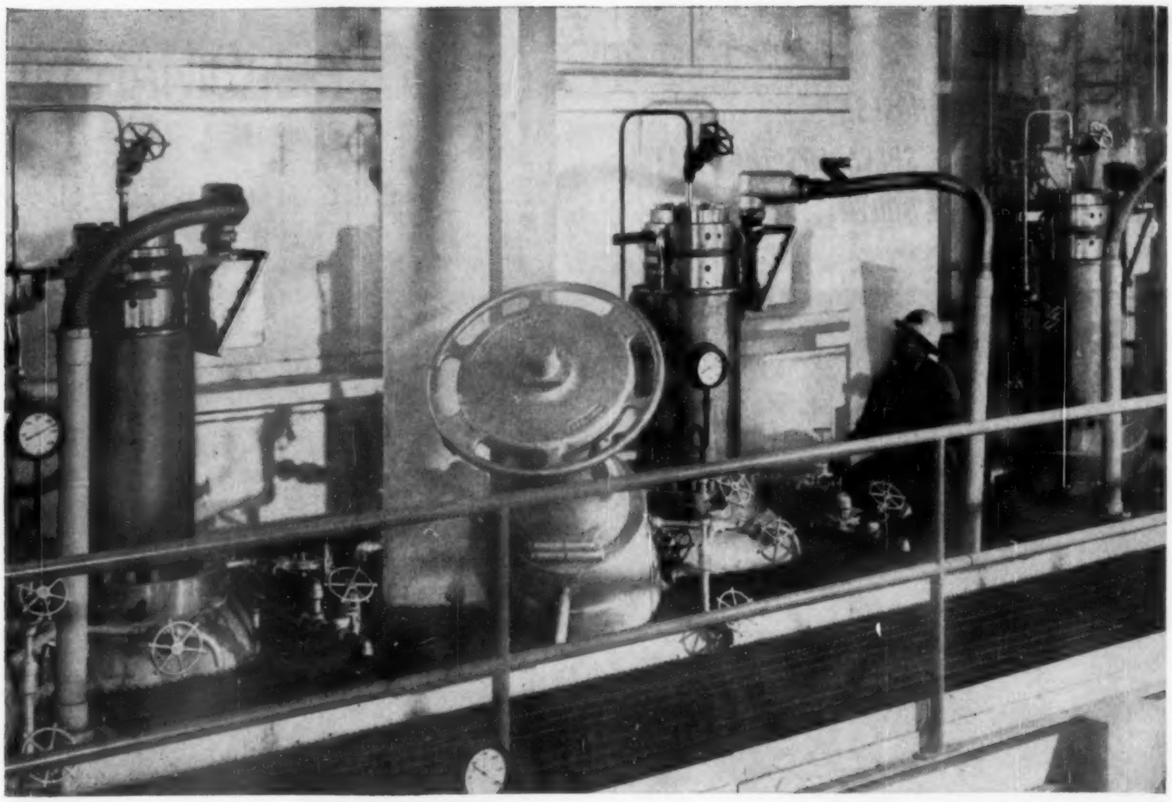


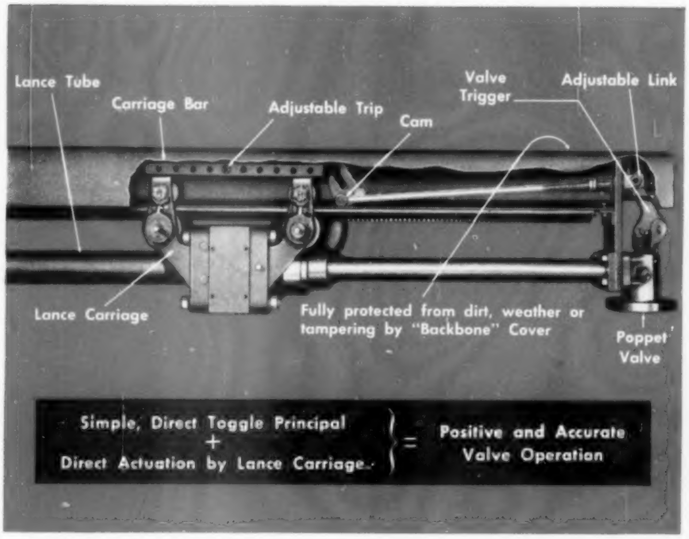


MECHANICALLY OPERATED POPPET TYPE VALVE

(WITH ADJUSTABLE PRESSURE CONTROL)

additional important features of the NEW

Diamond



Series 300 IK
LONG RETRACTING BLOWER

This valve was adopted for the new Series 300 IK because long experience has proved it the most satisfactory of all designs for severe blower service. More than 300,000 of this basic design are in use on various Diamond Blowers and have established notable service records. A recent improvement is more streamlined flow contours that permit higher flow rates with less pressure drop.

The direct mechanical linkage for actuating the valve offers the advantages of greater reliability and safety . . . in addition to more accurate control. Numerous other important features of the Series 300 IK are listed at the bottom of page. These are the reasons why this blower is establishing a new standard of efficiency, economy and dependability in cleaning heating surfaces that require a long retracting blower.

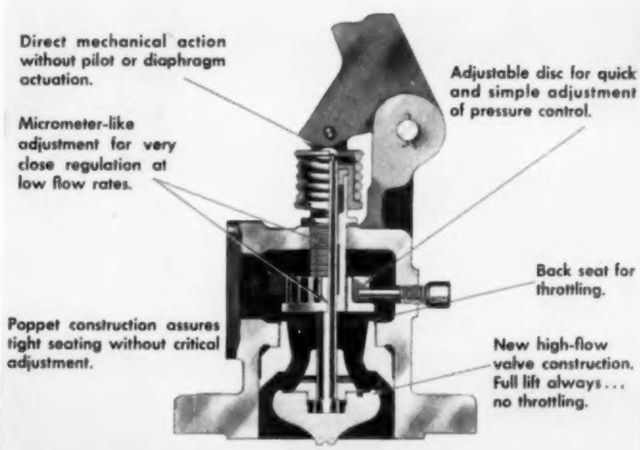
Bulletin 2111V tells much more about the Series 300 IK; ask your local Diamond office or write directly to Lancaster for a copy.

SERIES 300 IK—LONG RETRACTING BLOWER

OTHER ADVANTAGES OF SERIES 300 IK BLOWERS

- Backbone and Protective Cover
- Compact, Accessible Electric Power and Control Terminal Facilities
- Front End Single-Motor Drive
- Nozzle-Sweep-Every-Inch Cleaning Pattern
- Improved "Type A" Nozzle
- Positive Gear Carriage Drive
- Single Point Outboard Suspension
- Oversize Lance (Step-Tapered for Extra Long Travel)
- Auxiliary Carriages for Extra Long Travel
- Designed for Quick, Easy Servicing

No other blower gives you all these advantages.



FULL LIFT AND FULL OPENING OF VALVE AT ALL TIMES. No throttling at main seat. ALL throttling for pressure control is between back seat and adjustable disc.

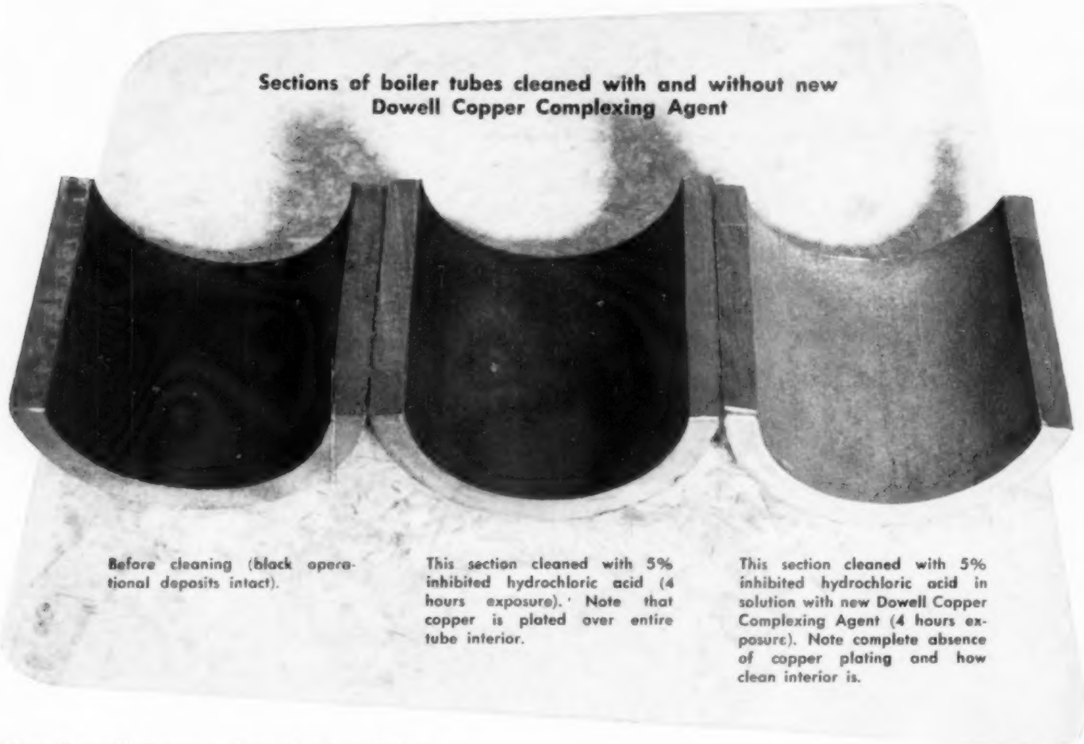
Diamond

DIAMOND POWER SPECIALTY CORP. LANCASTER, OHIO

Diamond Specialty Limited, Windsor, Ontario

7884

New single-stage chemical cleaning service removes copper, water-formed scale from boilers



Sections of boiler tubes cleaned with and without new Dowell Copper Complexing Agent

Before cleaning (black operational deposits intact).

This section cleaned with 5% inhibited hydrochloric acid (4 hours exposure). Note that copper is plated over entire tube interior.

This section cleaned with 5% inhibited hydrochloric acid in solution with new Dowell Copper Complexing Agent (4 hours exposure). Note complete absence of copper plating and how clean interior is.

New Dowell Copper Complexing Agent Prevents Copper "Plate-out" During Acid Cleaning

Dowell research has solved the problem of removing copper deposits, along with iron oxides and other water-formed deposits, in a *single-stage*, acid-fill boiler cleaning job. This single-stage chemical cleaning is made possible by a new copper-complexing agent*. When added to Dowell's regular cleaning solvents, this agent acts to dissolve copper deposits, and to complex copper ions so that they remain in solution in the spent acid and do not plate out on the newly cleaned metal.

Removal of copper from boiler tubes is of prime importance. Galvanic cells may be formed between the copper particles and exposed steel surfaces. Such cells may contribute to pitting during normal operation of the unit. Also copper deposits may interfere with heat transfer, leading to localized over-heating and sudden failure of the boiler tubes by rupture. Freshly plated copper may even slough and cause stoppage of the tubes.

Another distinct advantage of this new single-stage boiler cleaning service is in reduced boiler outage time. Boiler tubes can now be chemically cleaned—removing copper deposits in addition to water-formed scale and sludge in about one-half the time previously required to perform this service.

For complete information on how this new copper-complexing agent can help you, call the Dowell office near you. Or write Dowell Incorporated, Tulsa 1, Oklahoma.

*PATENT PENDING

have Dowell clean it chemically **DOWELL**

A SUBSIDIARY OF THE DOW CHEMICAL COMPANY